US009465009B2

(12) **United States Patent**
Tsuruno et al.

(10) **Patent No.: US 9,465,009 B2**
(45) **Date of Patent: Oct. 11, 2016**

(54) **ULTRASONIC MEASURING DEVICE, ULTRASONIC IMAGE DEVICE, AND METHOD FOR PROCESSING ULTRASONIC IMAGE**

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(73) Assignee: **Seiko Epson Corporation**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 373 days.

(21) Appl. No.: **14/290,443**

(22) Filed: **May 29, 2014**

(65) **Prior Publication Data**

US 2014/0352437 A1 Dec. 4, 2014

(30) **Foreign Application Priority Data**

May 31, 2013 (JP) 2013-116175

(51) **Int. Cl.**
G06K 9/00 (2006.01)
G01N 29/11 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G01N 29/11*** (2013.01); ***A61B 8/4483*** (2013.01); ***A61B 8/4494*** (2013.01); ***G01N 29/4472*** (2013.01); ***G01N 29/46*** (2013.01); ***G01N 29/52*** (2013.01); *A61B 8/4405* (2013.01); *A61B 8/4427* (2013.01); *G01N 2291/02475* (2013.01); *G01N 2291/044* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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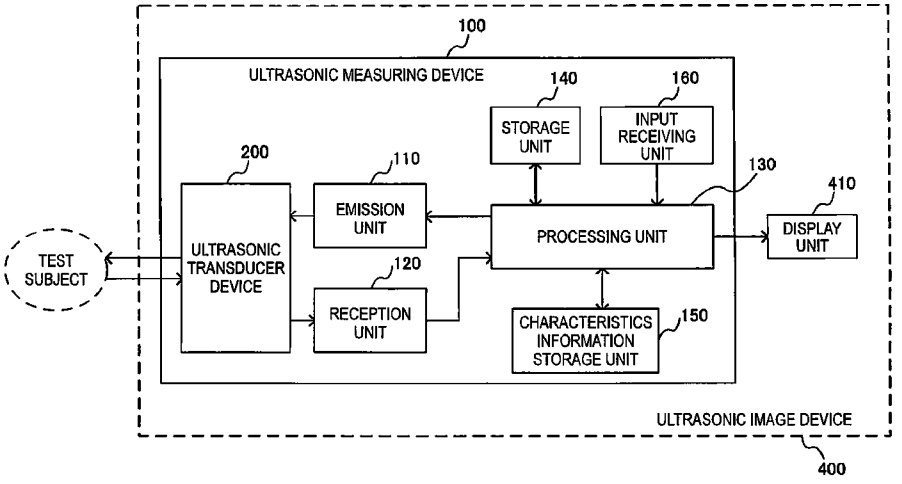
(57) **ABSTRACT**

An ultrasonic measuring device including: an ultrasonic transducer device; an emission unit for emitting an ultrasonic beam; a reception unit for receiving an ultrasonic echo reflected by a test subject; and a processing unit for processing reception, wherein the processing unit identifies a transfer function with respect to the ultrasonic transducer device and the test subject based on a first reception signal corresponding to an ultrasonic beam radiated to a first area in the test subject, a second reception signal corresponding to an ultrasonic beam radiated to a second area in the test subject, and a third reception signal corresponding to an ultrasonic beam radiated to a third area located between the first area and the second area in the test subject, and performs ultrasonic image generation processing including filter processing using a deconvolution filter including the transfer function performed on the reception signals.

20 Claims, 13 Drawing Sheets



(51) **Int. Cl.**

G01N 29/44	(2006.01)
G01N 29/46	(2006.01)
G01N 29/52	(2006.01)
A61B 8/00	(2006.01)

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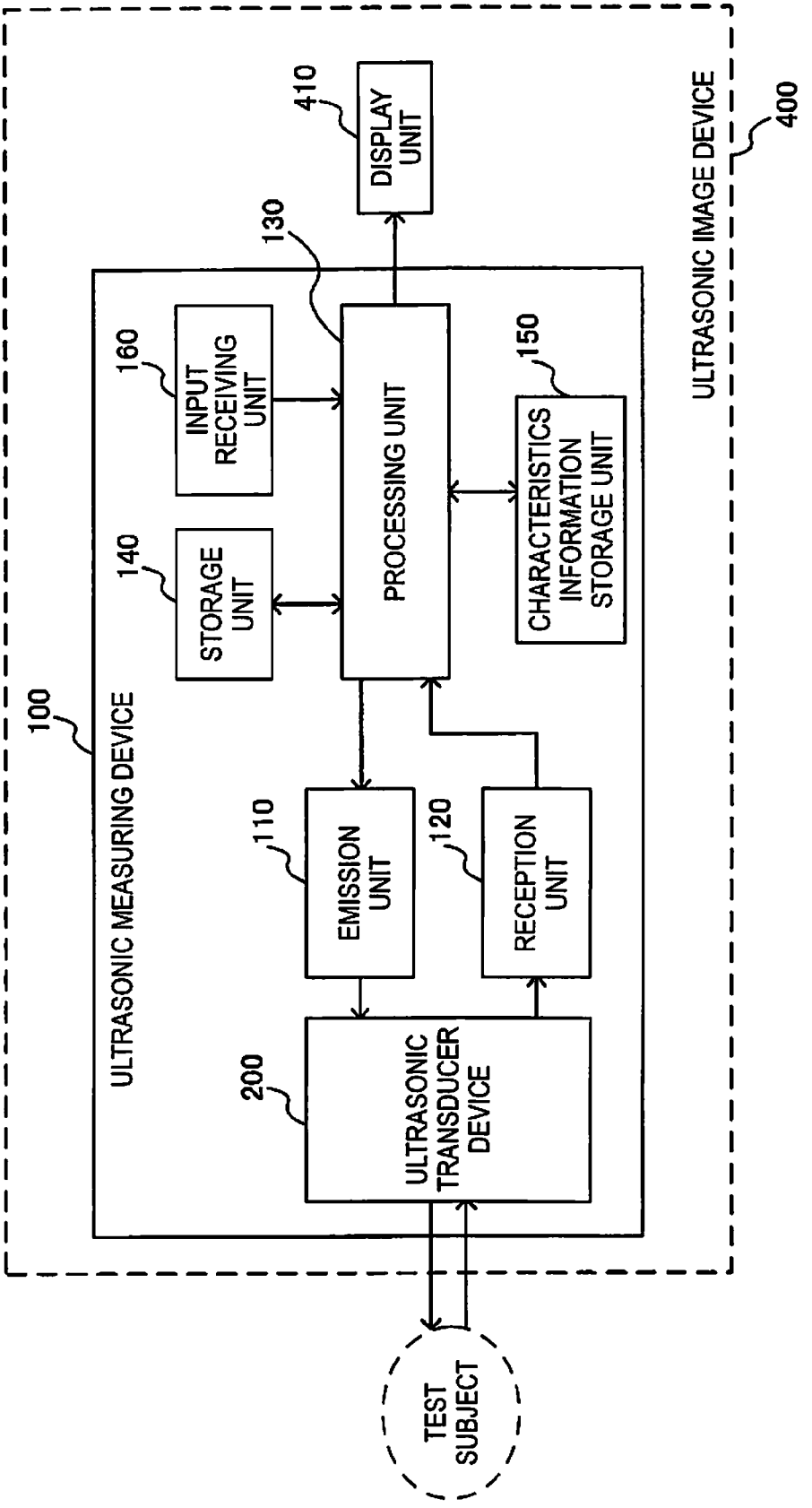
ULTRASONIC IMAGE DEVICE
400
DISPLAY UNIT
410
130
ULTRASONIC MEASURING DEVICE
100
INPUT RECEIVING UNIT
160
PROCESSING UNIT
CHARACTERISTICS INFORMATION STORAGE UNIT
150
STORAGE UNIT
140
EMISSION UNIT
110
RECEPTION UNIT
120
ULTRASONIC TRANSDUCER DEVICE
200
TEST SUBJECT

FIG. 1

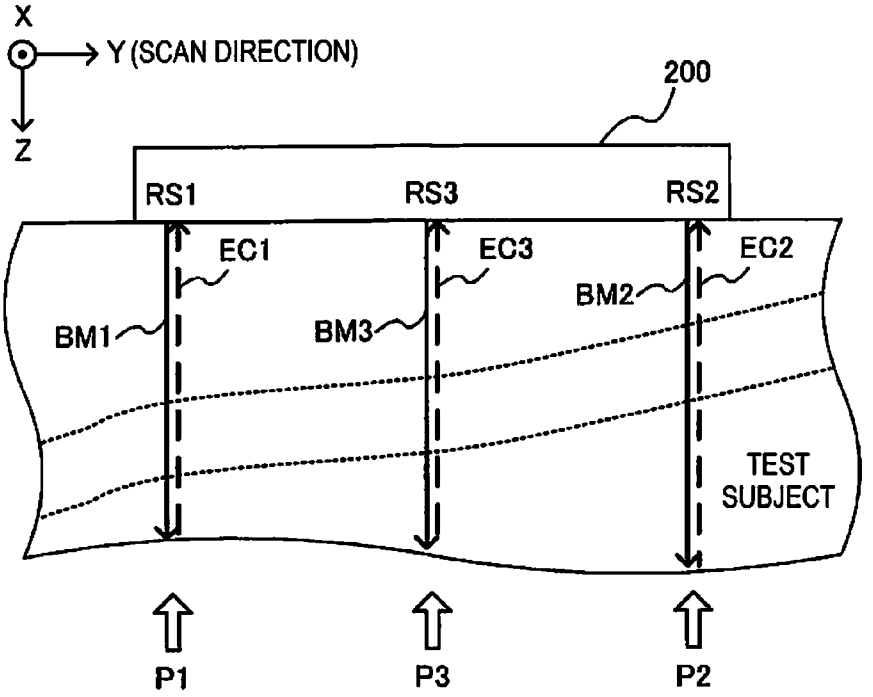
X
Y (SCAN DIRECTION)
Z
200
RS1
RS3
RS2
EC1
EC3
EC2
BM1
BM3
BM2
TEST SUBJECT
P1
P3
P2

FIG. 2A

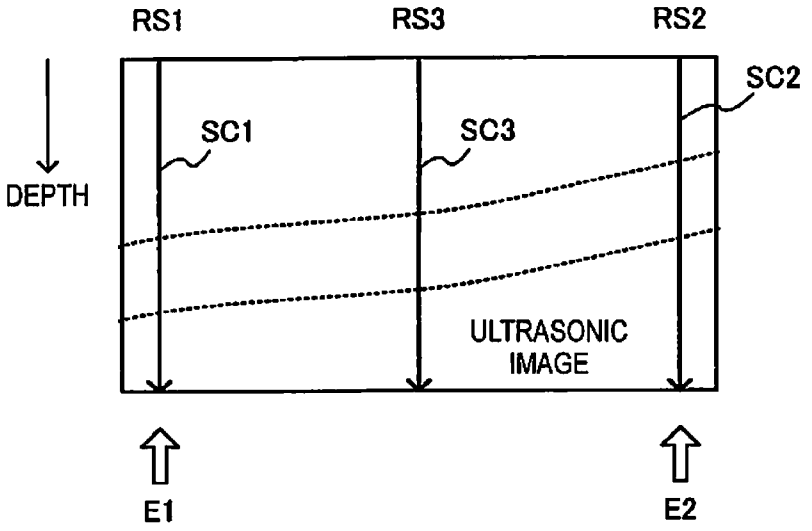
RS1
RS3
RS2
SC2
SC1
SC3
DEPTH
ULTRASONIC IMAGE
E1
E2

FIG. 2B

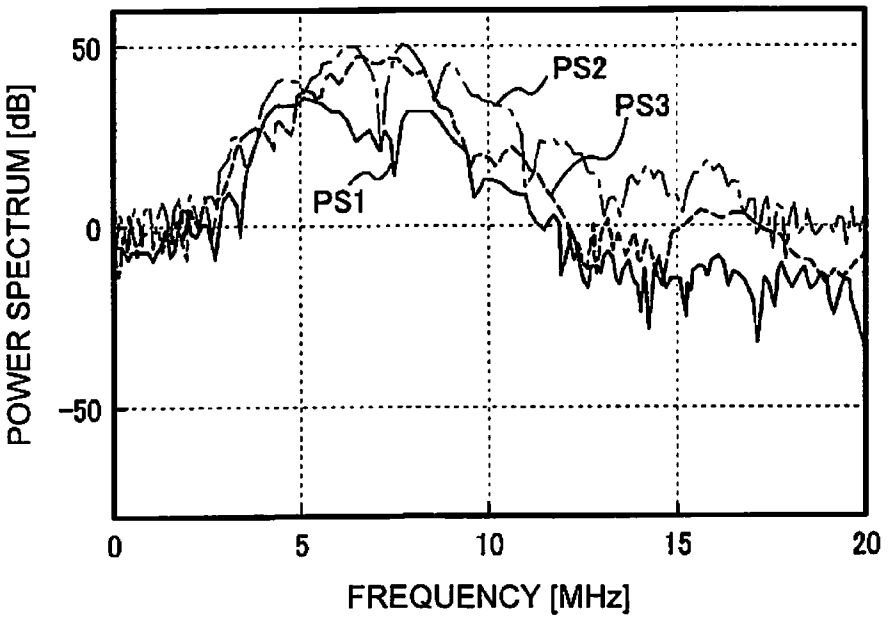
50
0
-50
POWER SPECTRUM [dB]
PS1
PS2
PS3
0
5
10
15
20
FREQUENCY [MHz]

FIG. 3A

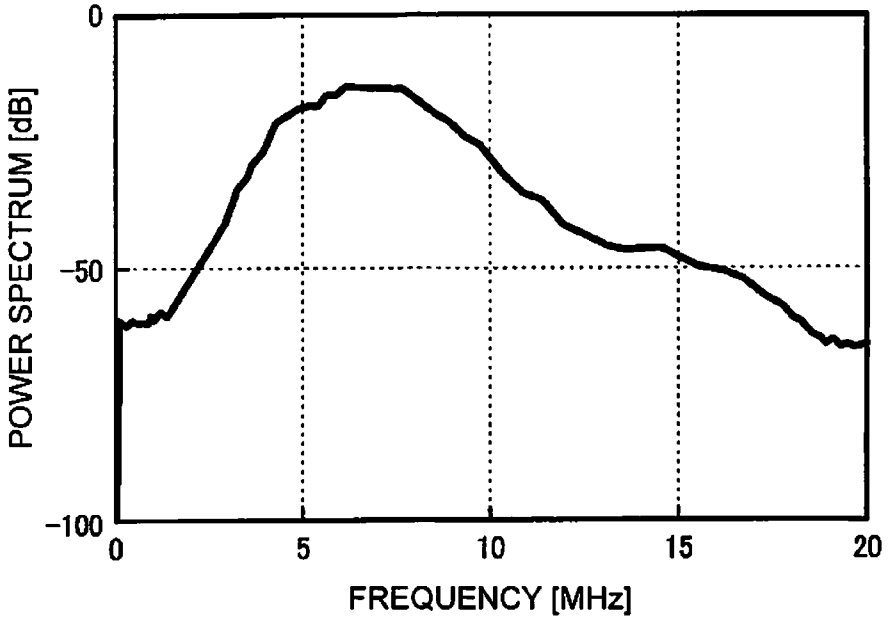
0
-50
-100
POWER SPECTRUM [dB]
0
5
10
15
20
FREQUENCY [MHz]

FIG. 3B

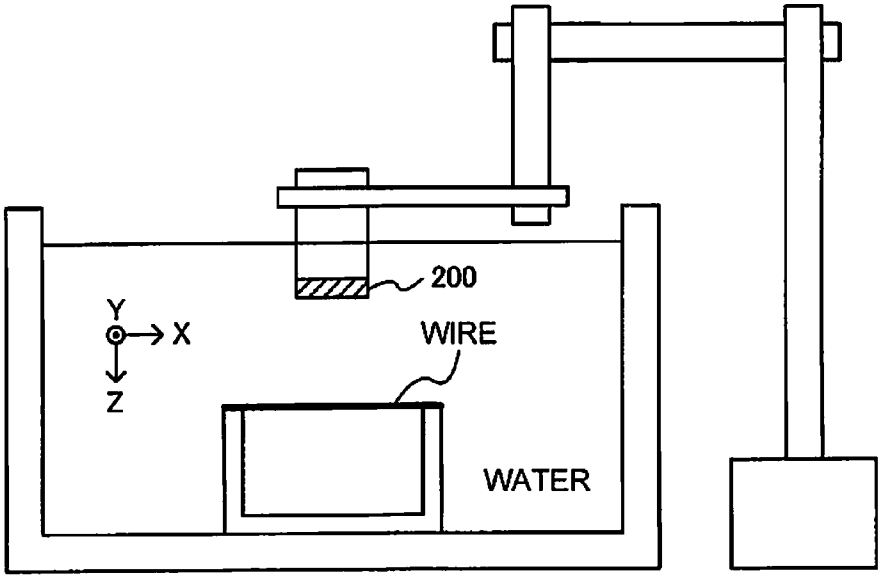
200
Y
X
Z
WIRE
WATER

FIG. 4

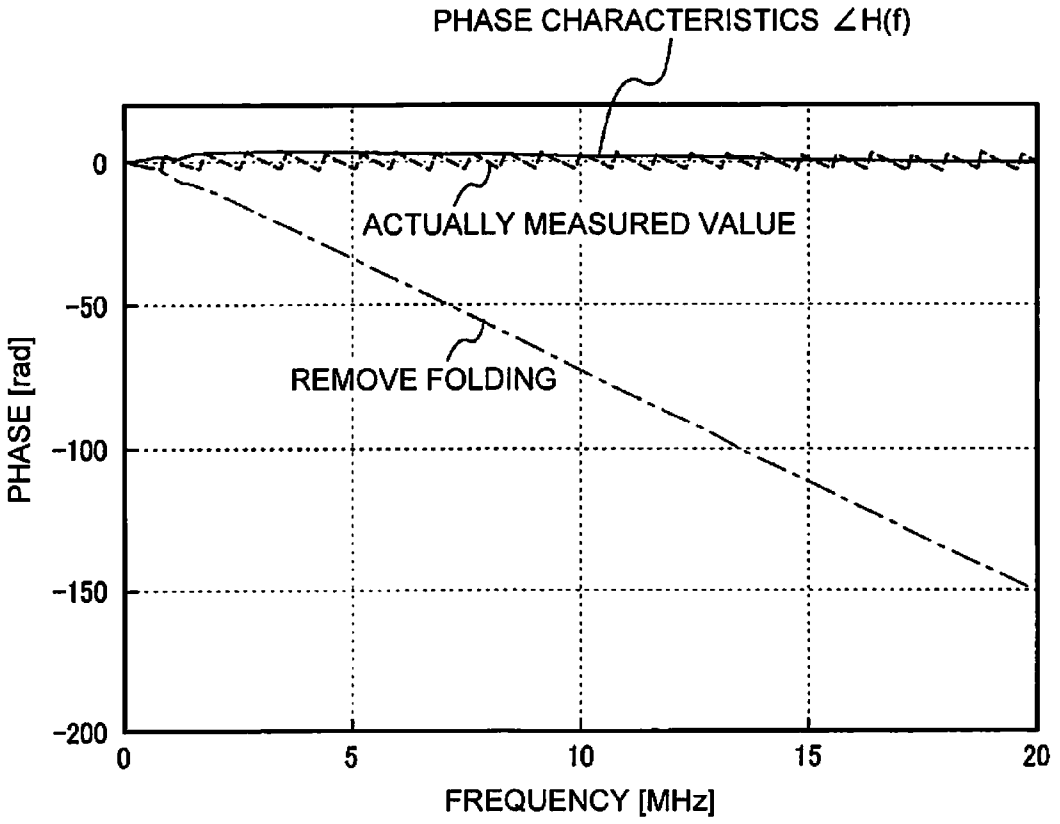
PHASE CHARACTERISTICS ∠H(f)
ACTUALLY MEASURED VALUE
REMOVE FOLDING
PHASE [rad]
0
-50
-100
-150
-200
0
5
10
15
20
FREQUENCY [MHz]

FIG. 5

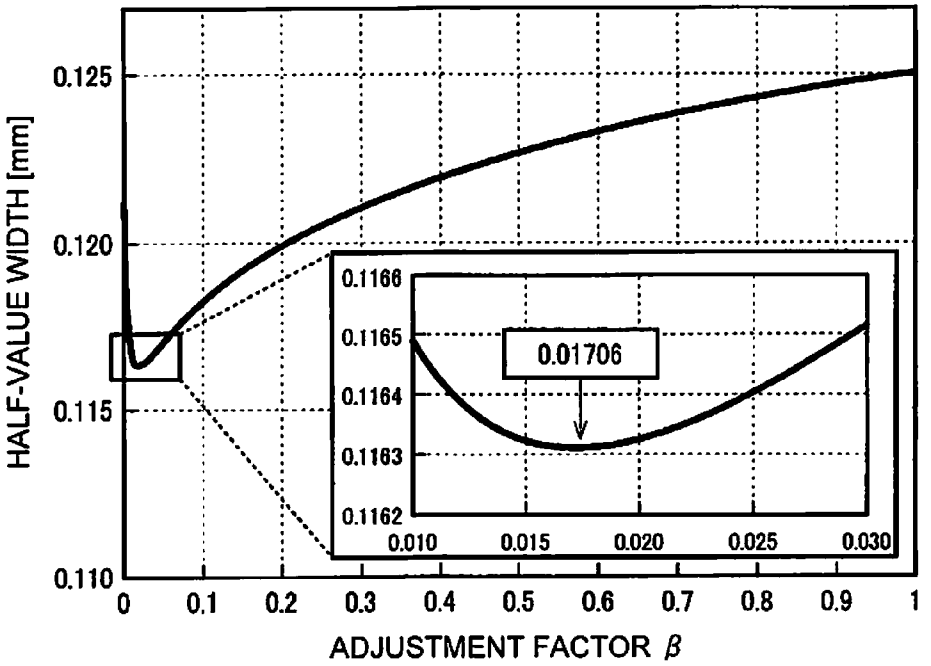
HALF-VALUE WIDTH [mm]
0.125
0.120
0.115
0.110
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
ADJUSTMENT FACTOR β
0.1166
0.1165
0.1164
0.1163
0.1162
0.01706
0.010
0.015
0.020
0.025
0.030

FIG. 6A

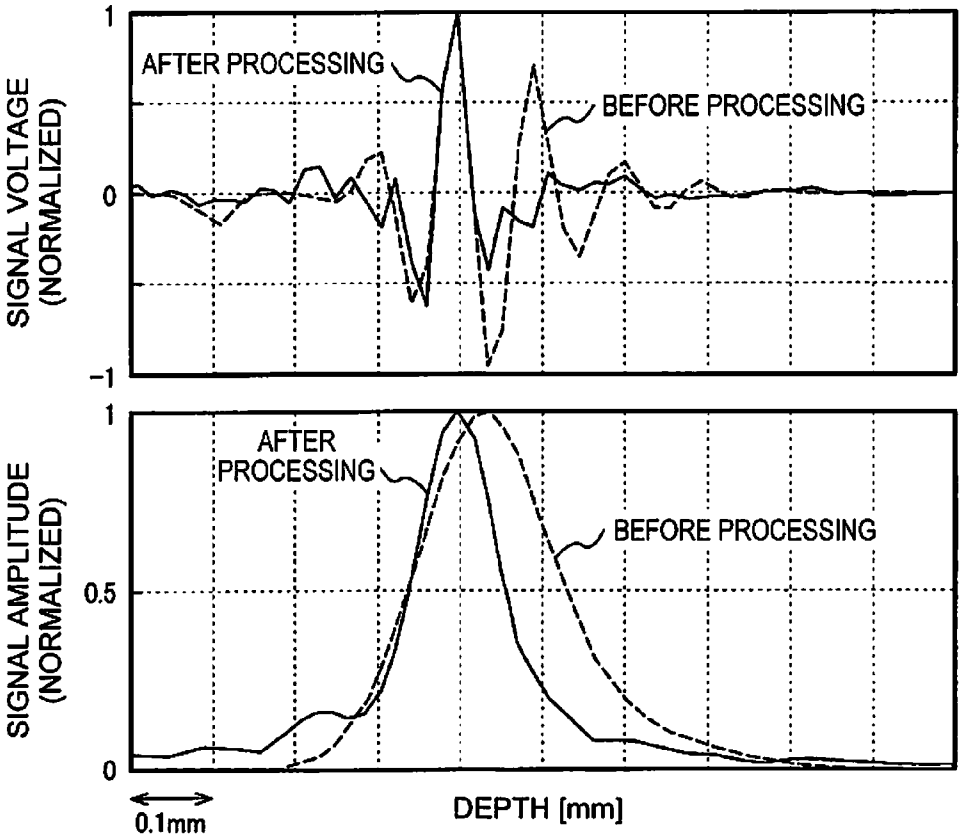
SIGNAL VOLTAGE (NORMALIZED)
1
0
-1
AFTER PROCESSING
BEFORE PROCESSING
SIGNAL AMPLITUDE (NORMALIZED)
1
0.5
0
AFTER PROCESSING
BEFORE PROCESSING
0.1mm
DEPTH [mm]

FIG. 6B

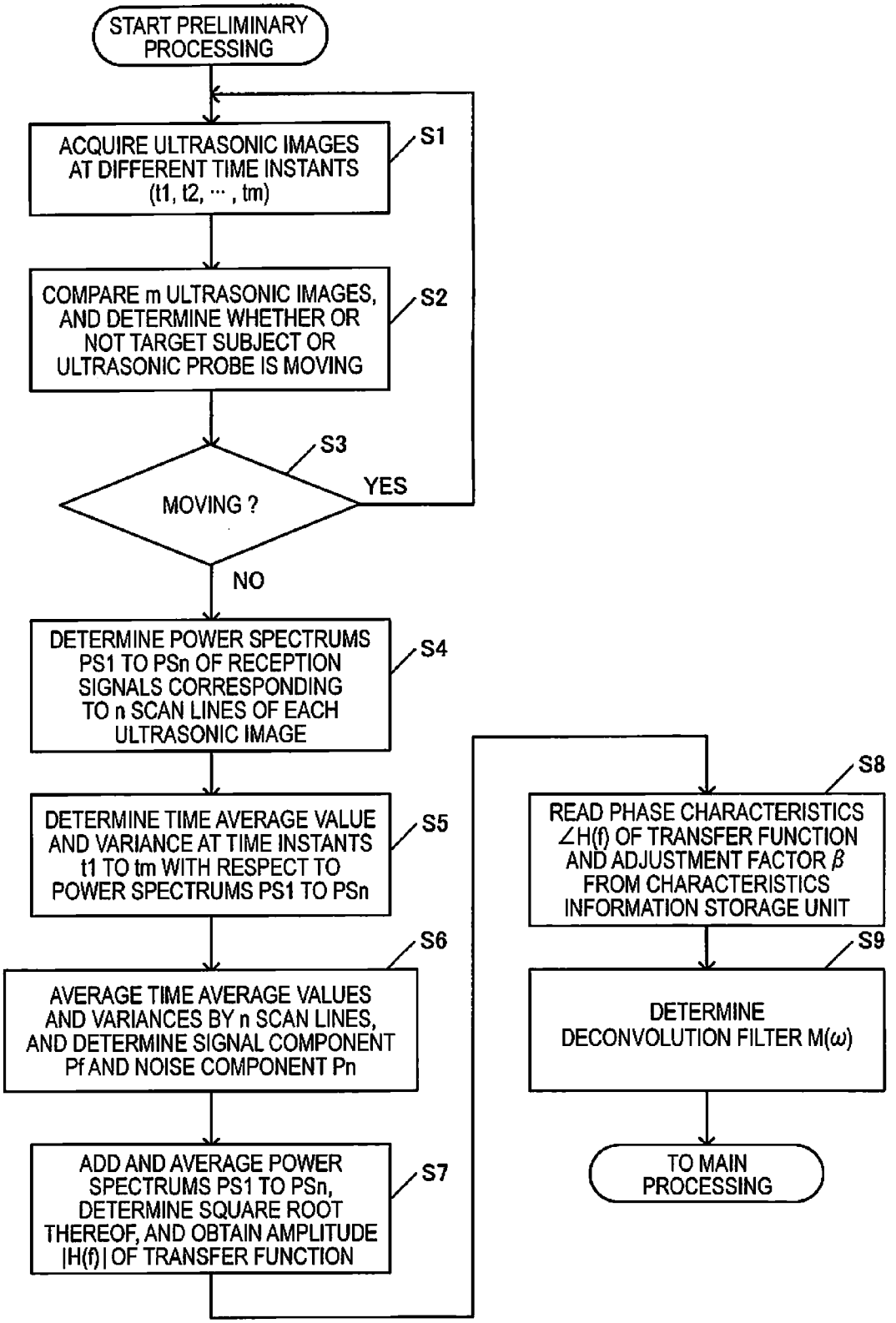
START PRELIMINARY PROCESSING
ACQUIRE ULTRASONIC IMAGES AT DIFFERENT TIME INSTANTS (t1, t2, ··· , tm)
S1
COMPARE m ULTRASONIC IMAGES, AND DETERMINE WHETHER OR NOT TARGET SUBJECT OR ULTRASONIC PROBE IS MOVING
S2
S3
MOVING ?
YES
NO
DETERMINE POWER SPECTRUMS PS1 TO PSn OF RECEPTION SIGNALS CORRESPONDING TO n SCAN LINES OF EACH ULTRASONIC IMAGE
S4
DETERMINE TIME AVERAGE VALUE AND VARIANCE AT TIME INSTANTS t1 TO tm WITH RESPECT TO POWER SPECTRUMS PS1 TO PSn
S5
AVERAGE TIME AVERAGE VALUES AND VARIANCES BY n SCAN LINES, AND DETERMINE SIGNAL COMPONENT Pf AND NOISE COMPONENT Pn
S6
ADD AND AVERAGE POWER SPECTRUMS PS1 TO PSn, DETERMINE SQUARE ROOT THEREOF, AND OBTAIN AMPLITUDE |H(f)| OF TRANSFER FUNCTION
S7
READ PHASE CHARACTERISTICS ∠H(f) OF TRANSFER FUNCTION AND ADJUSTMENT FACTOR β FROM CHARACTERISTICS INFORMATION STORAGE UNIT
S8
DETERMINE DECONVOLUTION FILTER M(ω)
S9
TO MAIN PROCESSING

FIG. 7

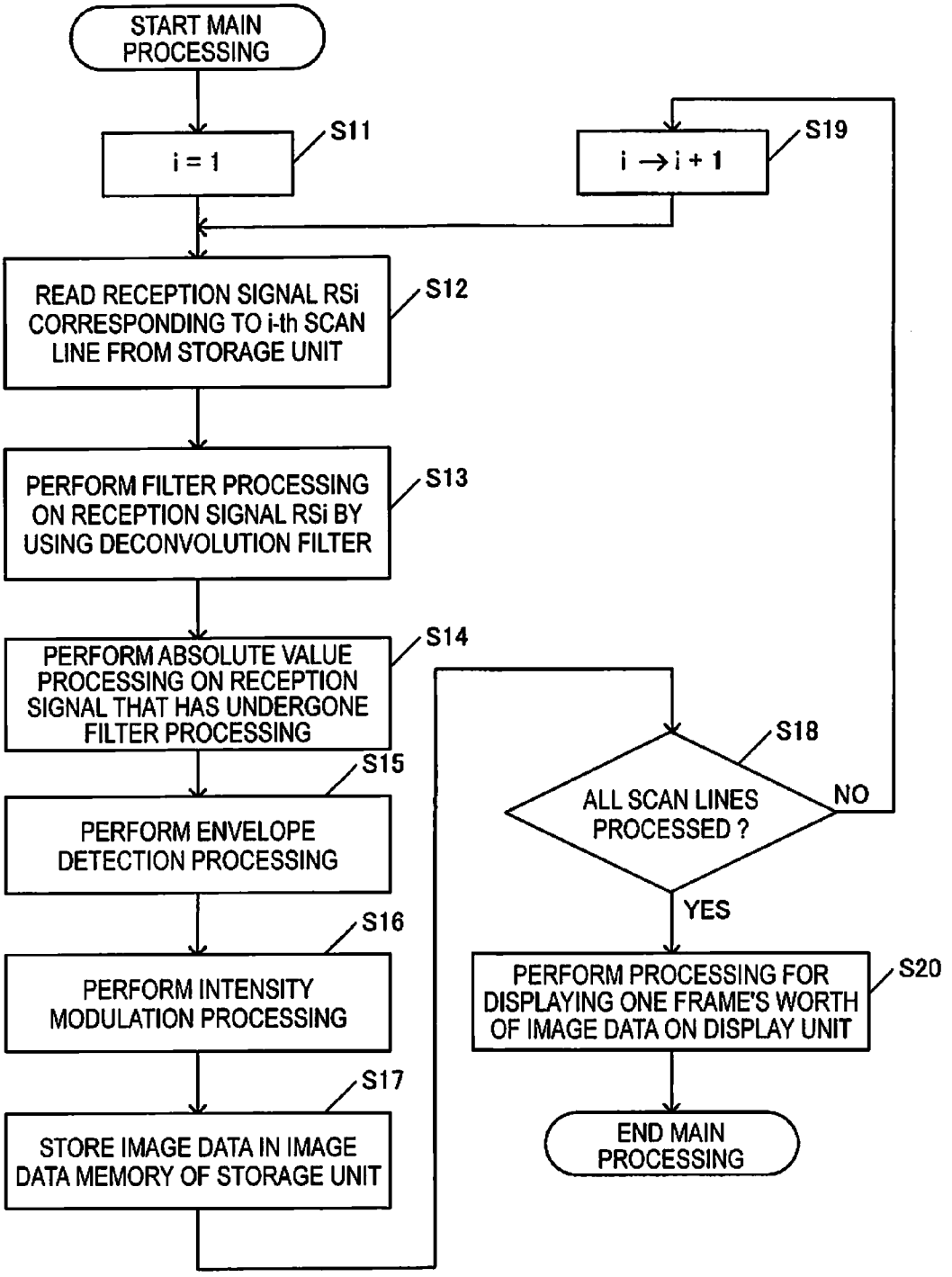
START MAIN PROCESSING
i = 1
S11
i → i + 1
S19
READ RECEPTION SIGNAL RSi CORRESPONDING TO i-th SCAN LINE FROM STORAGE UNIT
S12
PERFORM FILTER PROCESSING ON RECEPTION SIGNAL RSi BY USING DECONVOLUTION FILTER
S13
PERFORM ABSOLUTE VALUE PROCESSING ON RECEPTION SIGNAL THAT HAS UNDERGONE FILTER PROCESSING
S14
PERFORM ENVELOPE DETECTION PROCESSING
S15
PERFORM INTENSITY MODULATION PROCESSING
S16
STORE IMAGE DATA IN IMAGE DATA MEMORY OF STORAGE UNIT
S17
ALL SCAN LINES PROCESSED ?
S18
NO
YES
PERFORM PROCESSING FOR DISPLAYING ONE FRAME'S WORTH OF IMAGE DATA ON DISPLAY UNIT
S20
END MAIN PROCESSING

FIG. 8

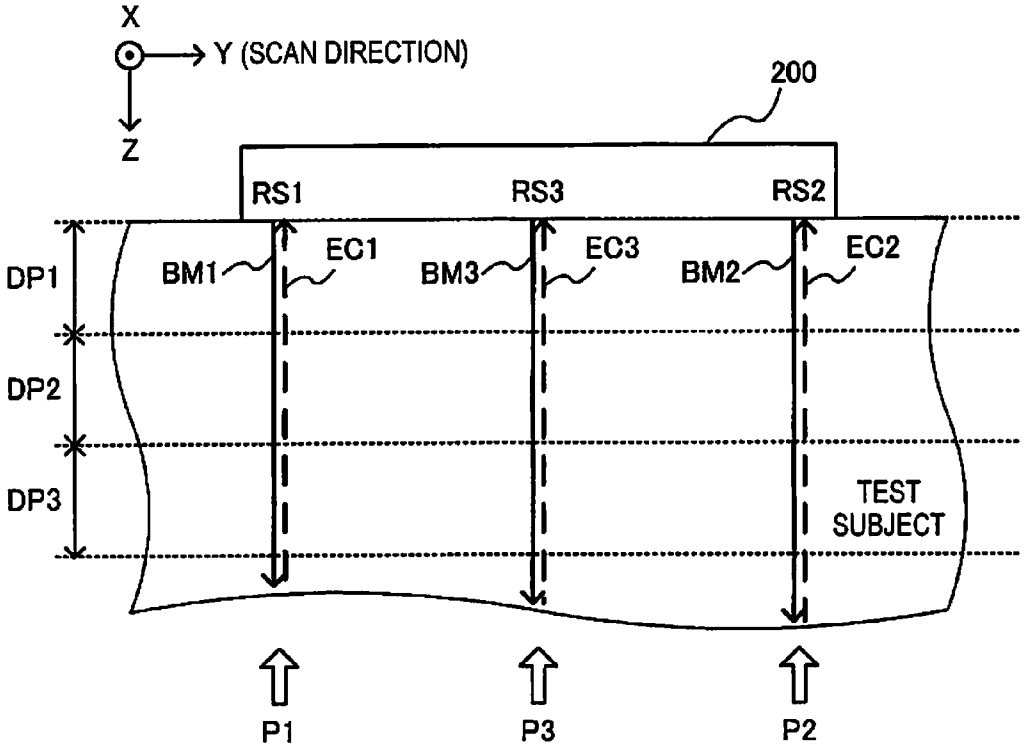
X
Y (SCAN DIRECTION)
Z
200
RS1
RS3
RS2
DP1
DP2
DP3
BM1
EC1
BM3
EC3
BM2
EC2
TEST SUBJECT
P1
P3
P2

FIG. 9A

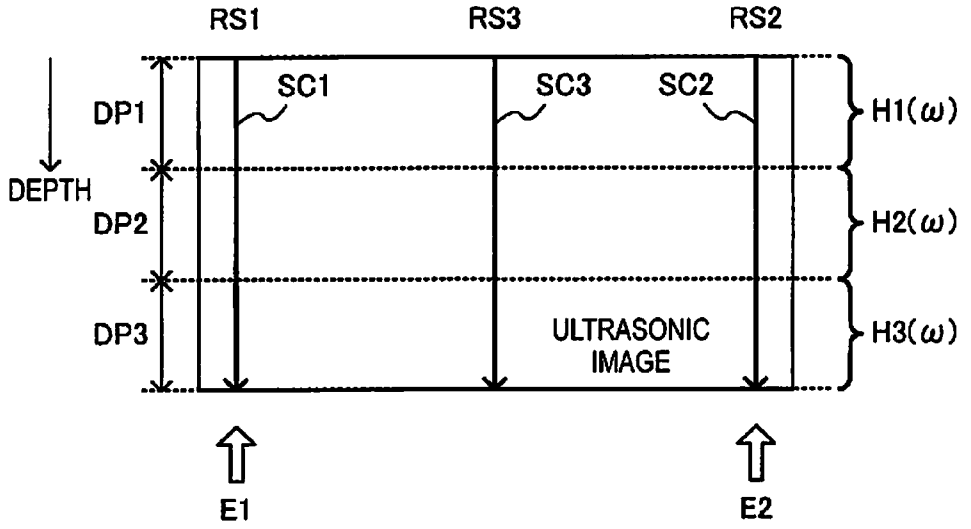
RS1
RS3
RS2
DEPTH
DP1
DP2
DP3
SC1
SC3
SC2
ULTRASONIC IMAGE
H1(ω)
H2(ω)
H3(ω)
E1
E2

FIG. 9B

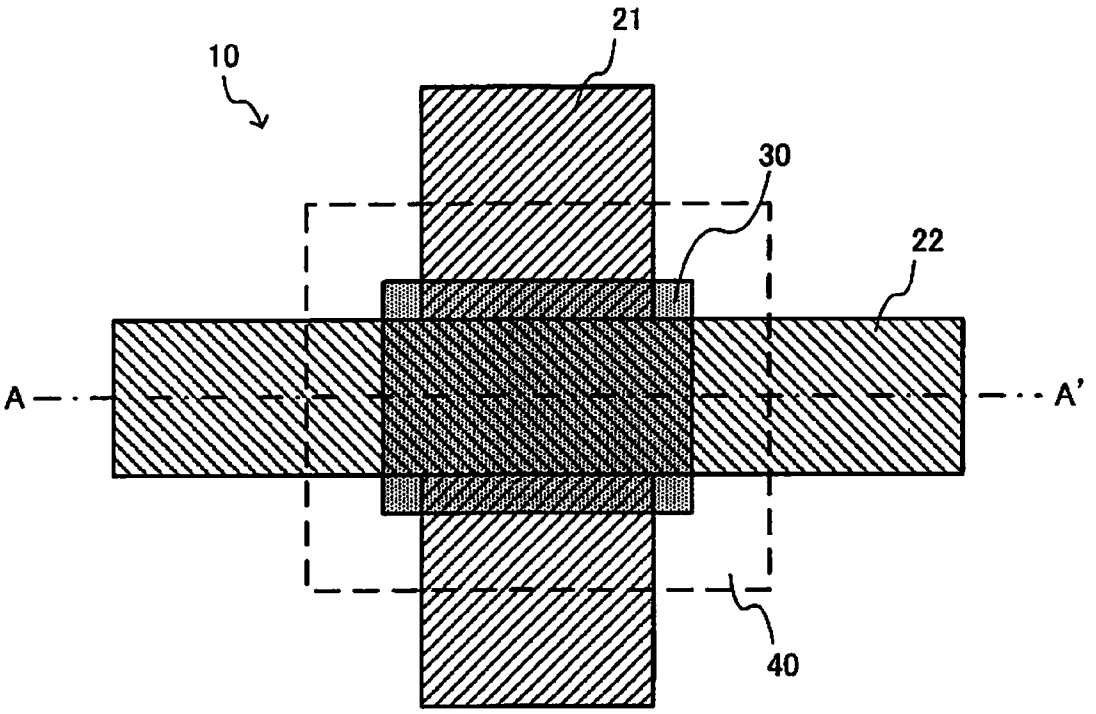

FIG.10A

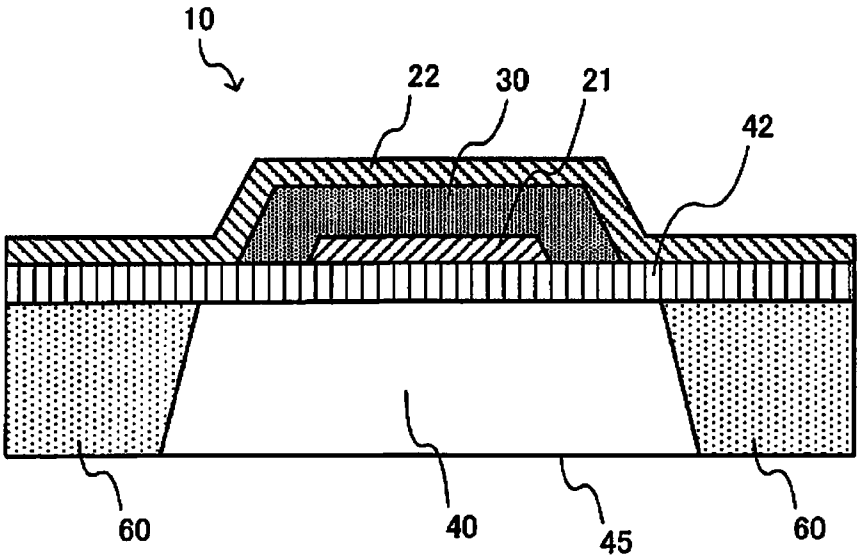

FIG.10B

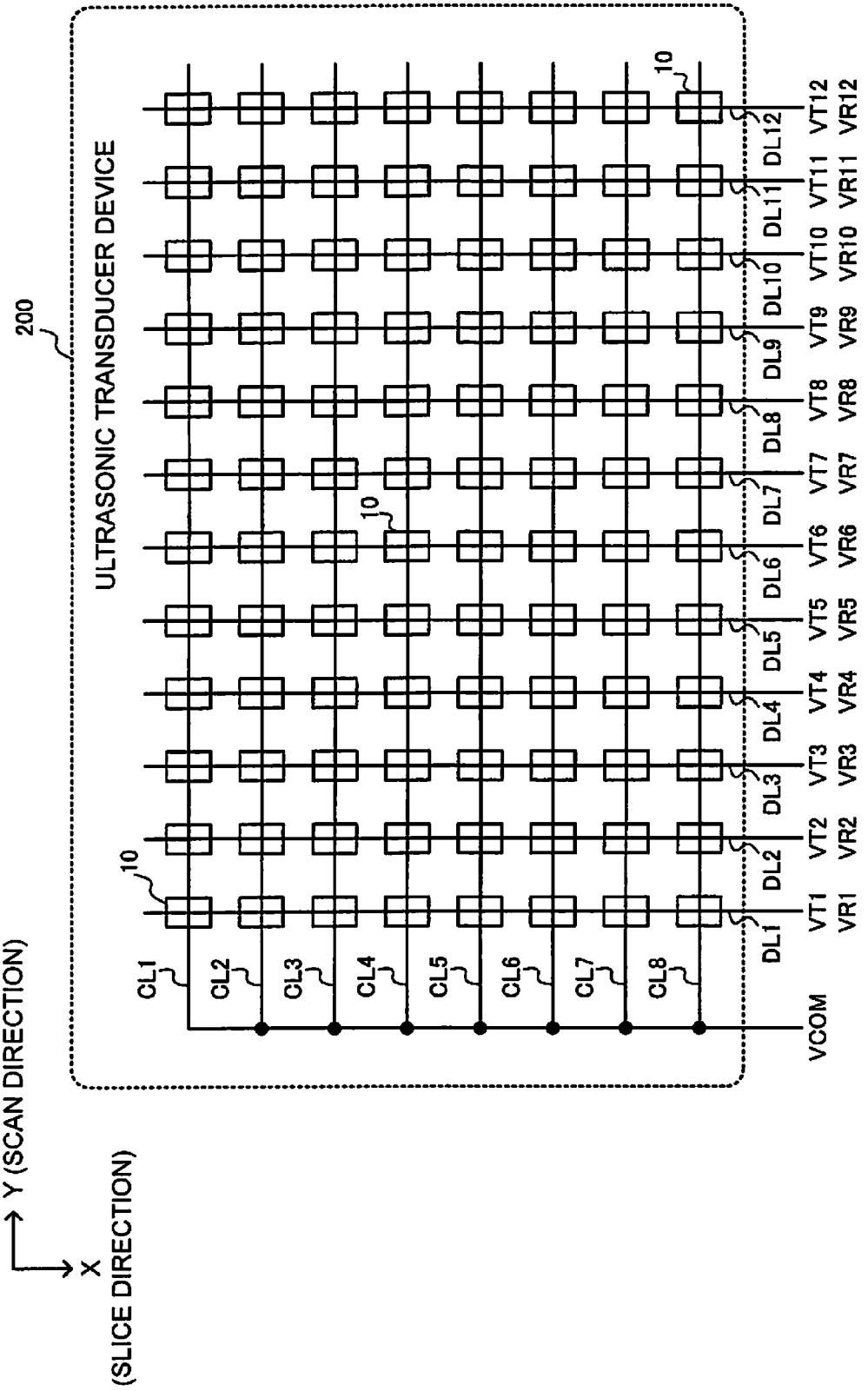
200
ULTRASONIC TRANSDUCER DEVICE
10
CL1
CL2
CL3
CL4
CL5
CL6
CL7
CL8
VCOM
DL1 VT1 VR1
DL2 VT2 VR2
DL3 VT3 VR3
DL4 VT4 VR4
DL5 VT5 VR5
DL6 VT6 VR6
DL7 VT7 VR7
DL8 VT8 VR8
DL9 VT9 VR9
DL10 VT10 VR10
DL11 VT11 VR11
DL12 VT12 VR12
Y (SCAN DIRECTION)
X
(SLICE DIRECTION)

FIG.11

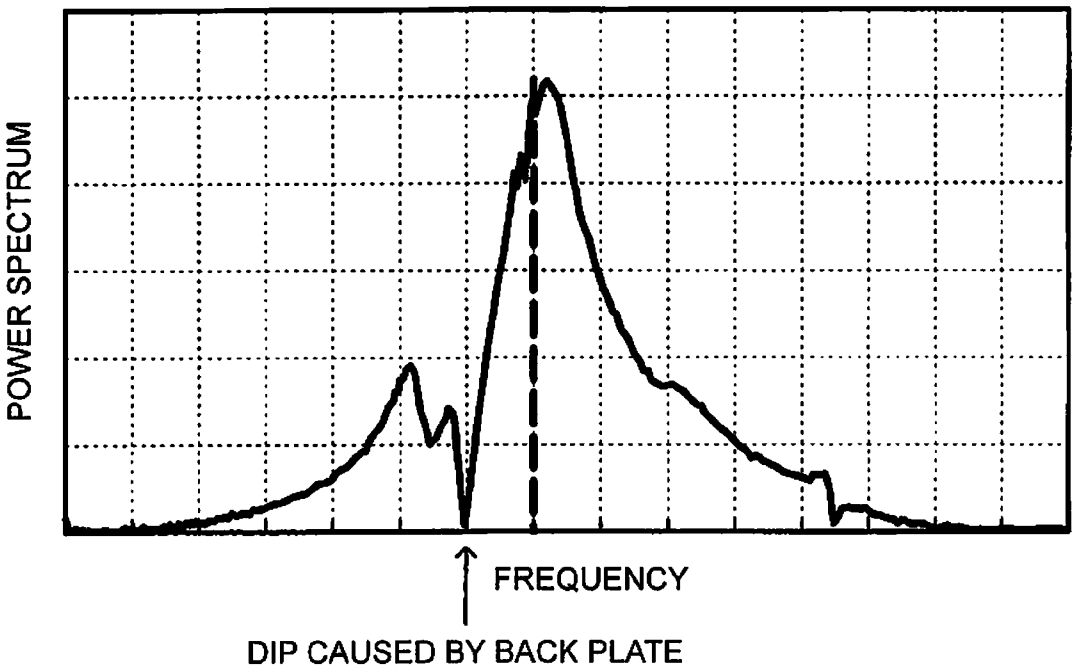

FIG.12

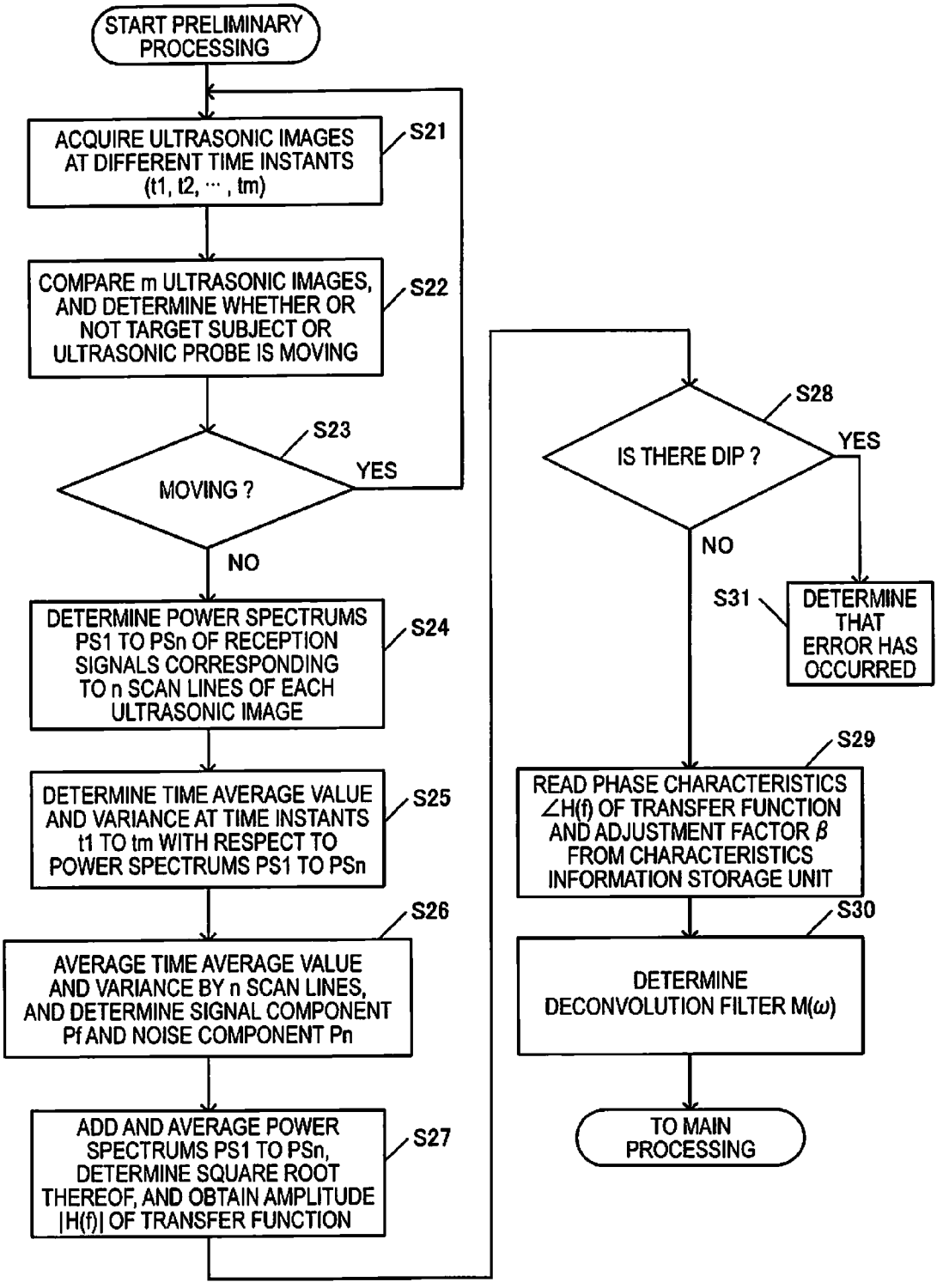
START PRELIMINARY PROCESSING
ACQUIRE ULTRASONIC IMAGES AT DIFFERENT TIME INSTANTS (t1, t2, ···, tm)
S21
COMPARE m ULTRASONIC IMAGES, AND DETERMINE WHETHER OR NOT TARGET SUBJECT OR ULTRASONIC PROBE IS MOVING
S22
MOVING ?
S23
YES
NO
DETERMINE POWER SPECTRUMS PS1 TO PSn OF RECEPTION SIGNALS CORRESPONDING TO n SCAN LINES OF EACH ULTRASONIC IMAGE
S24
DETERMINE TIME AVERAGE VALUE AND VARIANCE AT TIME INSTANTS t1 TO tm WITH RESPECT TO POWER SPECTRUMS PS1 TO PSn
S25
AVERAGE TIME AVERAGE VALUE AND VARIANCE BY n SCAN LINES, AND DETERMINE SIGNAL COMPONENT Pf AND NOISE COMPONENT Pn
S26
ADD AND AVERAGE POWER SPECTRUMS PS1 TO PSn, DETERMINE SQUARE ROOT THEREOF, AND OBTAIN AMPLITUDE |H(f)| OF TRANSFER FUNCTION
S27
IS THERE DIP ?
S28
YES
NO
DETERMINE THAT ERROR HAS OCCURRED
S31
READ PHASE CHARACTERISTICS ∠H(f) OF TRANSFER FUNCTION AND ADJUSTMENT FACTOR β FROM CHARACTERISTICS INFORMATION STORAGE UNIT
S29
DETERMINE DECONVOLUTION FILTER M(ω)
S30
TO MAIN PROCESSING

FIG.13

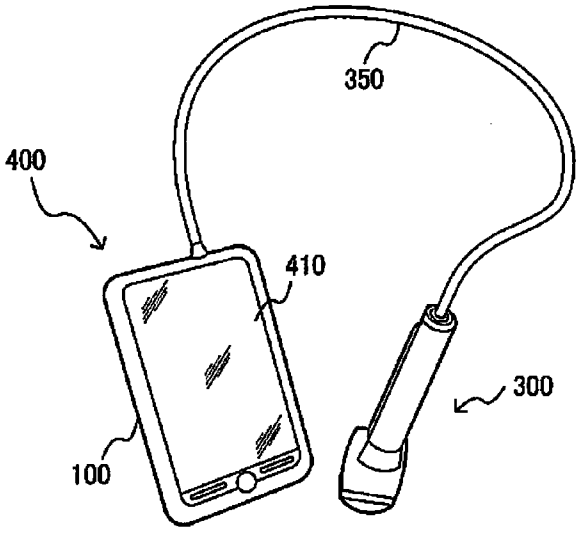

FIG.14A

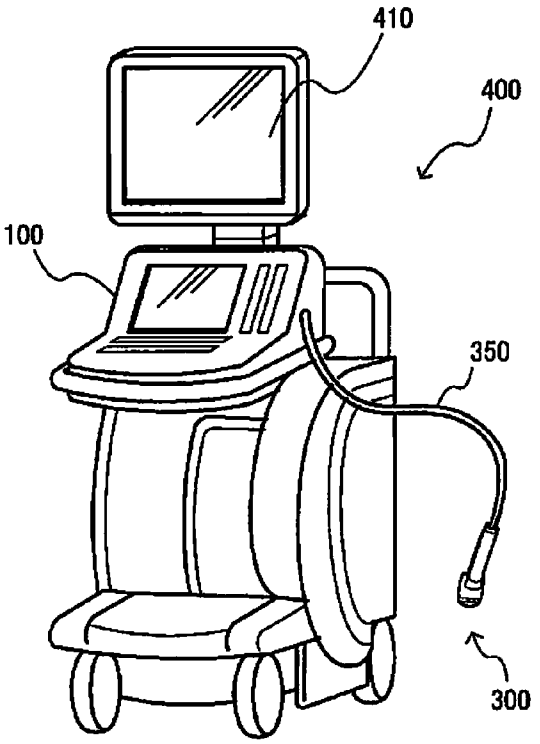

FIG.14B

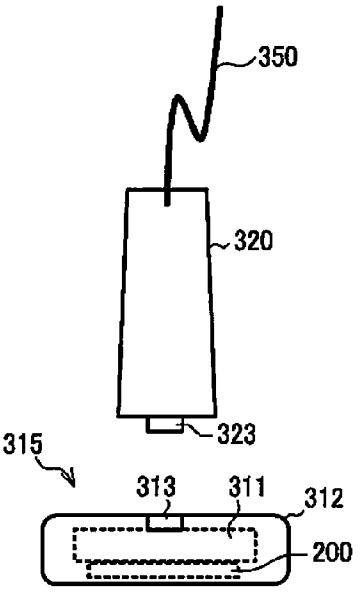

FIG.14C

ULTRASONIC MEASURING DEVICE, ULTRASONIC IMAGE DEVICE, AND METHOD FOR PROCESSING ULTRASONIC IMAGE

BACKGROUND

1. Technical Field

The present invention relates to an ultrasonic measuring device, an ultrasonic image device, and a method for processing an ultrasonic image, and the like.

2. Related Art

Ultrasonic diagnostic devices have a problem in that a signal obtained by emitting ultrasound from an ultrasonic transducer and receiving the ultrasound reflected by a target subject by the ultrasonic transducer convolves narrow band characteristics of the ultrasonic transducer, and thus the reflected signal has a wide pulse width even if the target subject is a spot, resulting in an ultrasonic image in which the target subject appears stretched.

To address this problem, in order to improve the resolution of ultrasonic images, a technique is known for obtaining an ultrasonic image having a high spatial resolution by removing the narrow band characteristics of the ultrasonic transducer convolved in the reception signal with the use of a filter (deconvolution filter) so as to reduce spreading of the reception signal.

For example, JP-A-2011-521730 discloses a technique in which in order to remove a dip included in a power spectrum of the reception signal when determining a transfer function with respect to individual scan lines, a cepstrum of the power spectrum is determined, and only a low frequency component is extracted therefrom. This method, however, requires a significant amount of calculation time and memory, and also has a problem in that the spreading of the reception signal cannot be reduced to a satisfactory level because phase characteristics are not included in the transfer function.

SUMMARY

An advantage of some aspects of the invention is to provide an ultrasonic measuring device, an ultrasonic image device, a method for processing an ultrasonic image, and the like that can efficiently generate an ultrasonic image having a high spatial resolution.

A first aspect of the invention relates to an ultrasonic measuring device including: an ultrasonic transducer device; an emission unit that performs processing for emitting an ultrasonic beam; a reception unit that performs processing for receiving an ultrasonic echo, which is obtained as a result of the ultrasonic beam being reflected by a test subject; and a processing unit that performs processing based on reception signals from the reception unit, wherein the processing unit identifies a transfer function with respect to the ultrasonic transducer device and the test subject based on a first reception signal corresponding to an ultrasonic echo of an ultrasonic beam radiated to a first area in the test subject, a second reception signal corresponding to an ultrasonic echo of an ultrasonic beam radiated to a second area in the test subject, and a third reception signal corresponding to an ultrasonic echo of an ultrasonic beam radiated to a third area in the test subject, the third area being located between the first area and the second area, and performs ultrasonic image generation processing including filter processing using a deconvolution filter including the transfer function performed on the reception signals.

According to this aspect of the invention, the processing unit can identify a transfer function of the ultrasonic transducer device and the test subject based on the first, second and third reception signals, and it is therefore possible to perform highly accurate filter processing using a deconvolution filter in a short processing time. As a result, an ultrasonic image having a high spatial resolution can be efficiently generated. The reception signal to be subjected to the filter processing is a reception signal used to generate an ultrasonic image. The reception signal may include the first, second and third reception signals, or may not include them.

Also, in the first aspect of the invention, the processing unit may obtain a first power spectrum of the first reception signal, a second power spectrum of the second reception signal, and a third power spectrum of the third reception signal, and determine an amplitude of the transfer function from the first power spectrum, the second power spectrum, and the third power spectrum.

According to this configuration, the processing unit can determine the amplitude of the transfer function of the ultrasonic transducer device and the test subject in a short processing time.

Also, in the first aspect of the invention, a characteristics information storage unit that stores information regarding phase characteristics of a transfer function with respect to the ultrasonic transducer device may be included, and the processing unit may perform the filter processing using a deconvolution filter by using the information regarding phase characteristics of the transfer function with respect to the ultrasonic transducer device stored in the characteristics information storage unit, and the amplitude of the transfer function determined from the first reception signal, the second reception signal, and the third reception signal.

According to this configuration, the processing unit can perform the filter processing using a deconvolution filter by using the transfer function that includes both the amplitude and the phase characteristics. It is therefore possible to generate a more highly accurate ultrasonic image.

Also, in the first aspect of the invention, it is possible that $M(\omega)=H^*(\omega)/(|H(\omega)|^2+\beta\times Pn(\omega)/Pf(\omega))$, where ω represents an angular frequency, $|H(\omega)|$ represents the amplitude of the transfer function, $H^*(\omega)$ represents a complex conjugate of the transfer function, $Pn(\omega)$ represents a power spectrum of noise components of the reception signals, $Pf(\omega)$ represents a power spectrum of signal components of the reception signals, β represents an adjustment factor value, and $M(\omega)$ represents the deconvolution filter.

According to this configuration, the processing unit can perform filter processing by using the deconvolution filter $M(\omega)$.

Also, in the first aspect of the invention, the characteristics information storage unit may further store the adjustment factor value β, and the processing unit may perform the filter processing using a deconvolution filter by using the adjustment factor value β stored in the characteristics information storage unit.

According to this configuration, the characteristics information storage unit can store an adjustment factor value β determined through, for example, ultrasonic measurement performed under water. Then, the processing unit can perform the filter processing using a deconvolution filter by using the adjustment factor value β stored in the characteristics information storage unit.

Also, in the first aspect of the invention, the characteristics information storage unit may store, as the adjustment factor value β, different values depending on the ultrasonic transducer device or the test subject.

According to this configuration, the characteristics information storage unit can store an adjustment factor value β determined for each ultrasonic transducer device, or an adjustment factor value β determined for each test subject.

Also, in the first aspect of the invention, the processing unit may perform the filter processing using a deconvolution filter by using the adjustment factor value β that varies depending on the ultrasonic transducer device or the test subject.

According to this configuration, the processing unit can perform the filter processing using a deconvolution filter by using a different adjustment factor value β according to the ultrasonic transducer device or the test subject, and it is therefore possible to generate a more highly accurate ultrasonic image.

Also, in the first aspect of the invention, the adjustment factor value β may be 0.2 or less.

According to this configuration, the processing unit can generate an ultrasonic image having a high spatial resolution while suppressing amplification of noise.

Also, in the first aspect of the invention, an input receiving unit that receives input of information regarding the adjustment factor value β may be included, and the processing unit may perform the filter processing using a deconvolution filter by using the information regarding the adjustment factor value β received by the input receiving unit.

According to this configuration, the processing unit can perform the filter processing using a deconvolution filter by using an adjustment factor value β input by the user.

Also, in the first aspect of the invention, the processing unit may determine the power spectrum $Pf(\omega)$ of the signal components based on time average values of power spectra of a plurality of reception signals measured at different time instants, and determine the power spectrum $Pn(\omega)$ of the noise components based on variances of the power spectra of the plurality of reception signals measured at the different time instants.

According to this configuration, the processing unit can determine the power spectrum $Pf(\omega)$ of signal components and the power spectrum $Pn(\omega)$ of noise components in a short processing time, and it is therefore possible to efficiently generate an ultrasonic image having a high spatial resolution.

Also, in the first aspect of the invention, the processing unit may identify a first transfer function to an n-th transfer function with respect to a first area to an n-th area (where n is an integer of 2 or greater) that have different depths in the test subject, and perform the filter processing by using a first deconvolution filter to an n-th deconvolution filter including the first transfer function to the n-th transfer function with respect to the first area to the n-th area.

According to this configuration, the processing unit can perform filter processing by using a deconvolution filter corresponding to each of a plurality of areas having different depths in the test subject, and it is therefore possible to generate an ultrasonic image having a higher spatial resolution.

Also, in the first aspect of the invention, the first area in the test subject may be an area corresponding to a first edge of the ultrasonic image, the second area in the test subject may be an area corresponding to a second edge of the ultrasonic image that is located opposite to the first edge, and the third area in the test subject may be an area located between the first edge and the second edge in the ultrasonic image.

According to this configuration, the processing unit can identify the transfer function based on reception signals of ultrasonic echoes from areas corresponding to two edges of the ultrasonic image and the center between the two edges.

Another aspect of the invention relates to an ultrasonic image device including: any one of the above-described ultrasonic measuring devices; and a display unit that displays the ultrasonic image.

Another aspect of the invention relates to an ultrasonic image processing method executed by a processing unit of an ultrasonic measuring device including: an ultrasonic transducer device; an emission unit that performs processing for emitting an ultrasonic beam; a reception unit that performs processing for receiving an ultrasonic echo, which is obtained as a result of the ultrasonic beam being reflected by a test subject; and the processing unit that performs processing based on reception signals from the reception unit, the method including: identifying a transfer function with respect to the ultrasonic transducer device and the test subject based on a first reception signal corresponding to an ultrasonic echo of an ultrasonic beam radiated to a first area in the test subject, a second reception signal corresponding to an ultrasonic echo of an ultrasonic beam radiated to a second area in the test subject, and a third reception signal corresponding to an ultrasonic echo of an ultrasonic beam radiated to a third area in the test subject, the third area being located between the first area and the second area, and performing filter processing using a deconvolution filter including the transfer function on the reception signals.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described with reference to the accompanying drawings, wherein like numbers reference like elements.

FIG. **1** shows an example of basic configurations of an ultrasonic measuring device and an ultrasonic image device.

FIGS. **2**A and **2**B are diagrams illustrating first, second and third reception signals for determining an amplitude of a transfer function.

FIG. **3**A shows an example of power spectra of the first, second and third reception signals. FIG. **3**B shows an example of an amplitude of a transfer function determined from the first, second and third reception signals.

FIG. **4** shows an example of ultrasonic measurement performed on a wire under water.

FIG. **5** shows an example of phase characteristics of the transfer function.

FIG. **6**A shows an example of an adjustment factor β. FIG. **6**B shows signal voltage and half-value width before and after filter processing.

FIG. **7** shows an example of a flowchart of preliminary processing.

FIG. **8** shows an example of a flowchart of main processing.

FIGS. **9**A and **9**B are diagrams illustrating identification of a transfer function according to a second configuration example of the ultrasonic measuring device.

FIGS. **10**A and **10**B show an example of a basic configuration of an ultrasonic transducer element.

FIG. **11** shows a configuration example of an ultrasonic transducer device.

FIG. **12** shows an example of a power spectrum of ultrasound radiated from a thin-film piezoelectric ultrasonic transducer element.

FIG. **13** shows an example of a flowchart of preliminary processing according to a third configuration example.

FIGS. **14**A and **14**B show examples of specific configurations of ultrasonic image devices. FIG. **14**C shows an example of a specific configuration of an ultrasonic probe.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

The following is a detailed description of preferred embodiments of the invention. Note that the embodiments described below are not intended to unduly limit the content of the invention recited in the claims, and all of the configurations described in the embodiments are not necessarily essential as solutions provided by the invention.

1. Basic Configuration Example of Ultrasonic Measuring Device

FIG. **1** shows an example of the basic configurations of an ultrasonic measuring device **100** and an ultrasonic image device **400** of this embodiment. The ultrasonic measuring device **100** of this embodiment includes an ultrasonic transducer device **200**, an emission unit **110**, a reception unit **120**, a processing unit **130**, a storage unit **140**, a characteristics information storage unit **150**, and an input receiving unit **160**. The ultrasonic image device **400** includes the ultrasonic measuring device **100** and a display unit **410**. Note that the ultrasonic measuring device **100** and the ultrasonic image device **400** of this embodiment are not limited to the configurations shown in FIG. **1**, and various modifications can be carried out, such as omitting some of the constituent elements, replacing some of the constituent elements with other constituent elements, and adding other constituent elements.

The ultrasonic transducer device **200** includes ultrasonic transducer elements. The ultrasonic transducer elements convert an emission signal, which is an electrical signal, into ultrasound, and convert an ultrasonic echo from a target subject (test subject) into an electrical signal. The ultrasonic transducer elements may be thin-film piezoelectric ultrasonic transducer elements, bulk piezoelectric ultrasonic transducer elements, CMUT (Capacitive Micromachined Ultrasonic Transducer) elements, or the like.

The emission unit **110** performs processing for emitting an ultrasonic beam. Specifically, the emission unit **110** outputs an emission signal (drive signal), which is an electrical signal, to the ultrasonic transducer device **200** under control of the processing unit **130**, and the ultrasonic transducer device **200** converts the emission signal, which is an electrical signal, into ultrasound and emits the ultrasound.

The reception unit **120** performs processing for receiving an ultrasonic echo obtained from an ultrasonic beam being reflected by the test subject. Specifically, the ultrasonic transducer device **200** converts an ultrasonic echo from the target subject into an electrical signal, and outputs the electrical signal to the reception unit **120**. The reception unit **120** performs reception processing, such as amplification, wave detection, A/D conversion and phase alignment, on a reception signal (analog signal), which is the electrical signal transmitted from the ultrasonic transducer device **200**, and outputs the reception signal (digital data), which is a signal obtained as a result of the reception processing, to the processing unit **130**.

The processing unit **130** performs processing for controlling the emission unit **110** and the reception unit **120**, and processing for generating an ultrasonic image based on reception signals from the reception unit **120**. Specifically, the processing unit **130** performs, on the reception signals, frequency analysis processing, filter processing using a deconvolution filter, absolute value processing, envelope detection processing, intensity modulation processing, and the like. The deconvolution filter will be described later in detail.

The processing unit **130** may be configured by, for example, a dedicated digital signal processor (DSP), or a general-purpose microprocessing unit (MPU). Alternatively, a part of processing executed by the processing unit **130** may be executed by a personal computer (PC).

The storage unit **140** is configured by, for example, a storage device such as, for example, a DRAM, and stores information regarding the amplitude of a transfer function identified based on reception signals and the power spectra of the reception signals. The information regarding the amplitude of a transfer function refers to information that can identify the amplitude of the transfer function, and may be, for example, a table or function that indicates the relationship between the amplitude of the transfer function and frequency, or a parameter.

The characteristics information storage unit **150** is configured by, for example, a nonvolatile storage device such as a flash memory, and stores information regarding the phase characteristics of the transfer function of the ultrasonic transducer device **200**, and information regarding an adjustment factor value β included in the deconvolution filter. The information regarding the phase characteristics of the transfer function refers to information that can identify the phase characteristics of the transfer function, and may be, for example, a table or function that indicates the relationship between phase and frequency, or a parameter that determines the phase characteristics. The information regarding the adjustment factor value β refers to information that can identify an adjustment factor value β, and may be, for example, an adjustment factor value β itself, or a function or parameter for determining the adjustment factor value β.

As will be described later, the phase characteristics of the transfer function and the adjustment factor value β can be determined by ultrasonic measurement performed on a wire (point scatterer) under water. The phase characteristics of the transfer function and the adjustment factor value β that have been determined may be stored in the characteristics information storage unit **150**. Also, the characteristics information storage unit **150** may store, as the adjustment factor value β, different values for different ultrasonic transducer devices **200** or test subjects. The processing unit **130** may perform filter processing using a deconvolution filter by using the adjustment factor value β that differs for each ultrasonic transducer device **200** or test subject. As used herein, the expression "differ for each test subject" encompasses a case in which the value varies depending on, for example, the measurement site in the human body subjected to measurement.

The input receiving unit **160** is an input device such as a keyboard or a touch panel, and receives an adjustment factor value β input by the user. The processing unit **130** can perform filter processing with a deconvolution filter by using the adjustment factor value β received by the input receiving unit **160**.

The display unit **410** is a display device such as a liquid crystal display, and displays an ultrasonic image (for example, B mode image) generated by the processing unit **130**.

2. Identification of Transfer Function

A description will be given of identification of the amplitude of a transfer function in a first configuration example of the ultrasonic measuring device **100** of this embodiment. FIGS. **2**A and **2**B are diagrams illustrating a first reception signal, a second reception signal and a third reception signal

for determining the amplitude of a transfer function. As shown in FIG. **2**A, a first reception signal RS**1** is a reception signal corresponding to an ultrasonic echo EC**1** of an ultrasonic beam BM**1** radiated to a first area P**1** of a test subject. The first area P**1** of the test subject is, as shown in FIG. **2**B, an area corresponding to a first edge E**1** of an ultrasonic image (one frame image). That is, the first reception signal RS**1** is a reception signal corresponding to a single scan line SC**1** located in the first edge E**1** of the ultrasonic image.

The edge of an ultrasonic image refers to an area where scanning with ultrasonic beams starts or ends in one frame of ultrasonic image (for example, B mode image), and includes a plurality of scan lines. Each scan line is a collection of pixels arranged along a single straight line extending in a depth direction in one frame of ultrasonic image. The single scan line SC**1** located in the first edge E**1** of the ultrasonic image does not necessarily need to be the leftmost scan line in, for example, FIG. **2**A, and may be one of a plurality of scan lines located in the first edge E**1**.

Likewise, a second reception signal RS**2** is a reception signal corresponding to an ultrasonic echo EC**2** of an ultrasonic beam BM**2** radiated to a second area P**2** of the test subject. The second area P**2** of the test subject is an area corresponding to a second edge E**2** of the ultrasonic image, which is located opposite to the first edge E**1**. That is, the second reception signal RS**2** is a reception signal corresponding to a single scan line SC**2** located in the second edge E**2** of the ultrasonic image.

A third reception signal RS**3** is a reception signal corresponding to an ultrasonic echo EC**3** of an ultrasonic beam BM**3** radiated to a third area P**3** between the first area P**1** and the second area P**2** of the test subject. The third area P**3** of the test subject is an area that is located between the first edge E**1** and the second edge E**2** of the ultrasonic image. That is, the third reception signal RS**3** is a reception signal corresponding to a single scan line (for example, a scan line at the center in the ultrasonic image) SC**3** located between the first edge E**1** and the second edge E**2** of the ultrasonic image.

The processing unit **130** determines the amplitude of a transfer function from the first, second and third reception signals in the following manner.

The processing unit **130** performs frequency analysis on the first, second and third reception signals RS**1**, RS**2** and RS**3** so as to obtain a first power spectrum, a second power spectrum and a third power spectrum. Then, from the first, second and third power spectra, the amplitude of a transfer function is determined with respect to the ultrasonic transducer device **200** and the test subject. Specifically, the processing unit **130** averages the first, second and third power spectra, and defines the square root of the averaged power spectrum as the amplitude of the transfer function.

The foregoing stated that the first, second and third reception signals RS**1**, RS**2** and RS**3** are reception signals respectively corresponding to the scan lines SC**1**, SC**2** and SC**3** of the ultrasonic image, but they do not necessarily need to be reception signals corresponding to the scan lines of the ultrasonic image. For example, the first, second and third reception signals RS**1**, RS**2** and RS**3** may be A mode waveforms of ultrasonic echoes from the first, second and third areas P**1**, P**2** and P**3** of the test subject.

As the reception signals for determining the amplitude of a transfer function, it is possible to use four or more reception signals corresponding to ultrasonic echoes of ultrasonic beams radiated to four or more areas of the test subject. In this case, power spectra PS**1**(f) to PSn(f) of the first to n-th (where n is an integer of 4 or greater) reception signals RS**1** to RSn are averaged, and the square root of the averaged power spectrum is defined as the amplitude |H(f)| of the transfer function.

FIG. **3**A shows an example of the power spectra PS**1**(f), PS**2**(f) and PS**3**(f) of the first, second and third reception signals RS**1**, RS**2** and RS**3**. Here, f represents frequency.

As can be seen from FIG. **3**A, each of the power spectra PS**1**(f), PS**2**(f) and PS**3**(f) includes dips caused by interference of a plurality of reflected ultrasonic waves from the test subject. The frequency at which such a dip occurs depends on the positional relationship between a plurality of scatterers in the test subject. The scatterer arrangement varies depending on the measurement position, and thus the frequency at which a dip occurs also varies among the first, second and third reception signals RS**1**, RS**2** and RS**3**. Accordingly, the first, second and third power spectra PS**1**(f), PS**2**(f) and PS**3**(f) are averaged, and the square root thereof is obtained so as to smooth the dips, and the amplitude of a desired transfer function, or in other words, an amplitude |H(f)| of the transfer function of the ultrasonic transducer device **200** and the test subject is thereby obtained.

FIG. **3**B shows an example of the amplitude |H(f)| of the transfer function determined from the first, second and third reception signals RS**1**, RS**2** and RS**3**. It can be seen from FIG. **3**B that the dips are smoothened, and the influence of the dips is removed.

The amplitude |H(f)| of the transfer function determined in the above-described manner represents not only the transfer characteristics of the ultrasonic transducer device **200**, but also the transfer characteristics of the test subject (biological tissue). Accordingly, the amplitude |H(f)| of the transfer function has characteristics that varies depending on the measurement site in the test subject. For this reason, in the actual ultrasonic measurement, the processing unit **130** determines the amplitude |H(f)| of a transfer function corresponding to the measurement site in the test subject for each ultrasonic measurement, and performs filter processing using a deconvolution filter by using the amplitude |H(f)| of the transfer function. By doing so, it is possible to obtain a highly accurate amplitude |H(f)| that also includes transfer characteristics of the measurement site in the test subject.

Next is a description of identification of phase characteristics ∠H(f) of the transfer function. The phase characteristics ∠H(f) of the transfer function can be determined by ultrasonic measurement performed on a wire (point scatterer) under water. In the biological tissue, the amplitude of ultrasound attenuates depending on the frequency, but the phase characteristics are not so affected by attenuation that depends on the frequency, as compared to the amplitude. Accordingly, the phase characteristics of the transfer function of the ultrasonic transducer device measured under water can be regarded as the phase characteristics of the transfer function of the biological tissue.

FIG. **4** shows an example of ultrasonic measurement performed on a wire under water. As shown in FIG. **4**, ultrasound is radiated from an ultrasonic transducer device **200** toward a wire having a small diameter (for example, a diameter of 13 μm) provided under water so as to perform ultrasonic measurement. The ultrasonic transducer device **200** is provided such that Y direction corresponds to the scan direction. The wire is provided so as to extend in X direction. Because ultrasonic beams are scanned in the Y direction, the wire can be regarded as a point scatterer.

FIG. **5** shows an example of the phase characteristics ∠H(f) of a transfer function determined through ultrasonic

measurement performed on a wire under water. The broken line shown in FIG. **5** indicates actually measured phase data, from which it can be seen that folding has occurred. The dashed dotted line shown in FIG. **5** indicates phase data from which the influence of folding has been removed by unwrapping the phase. Furthermore, an amount of change in the phase due to propagation delay is removed, and thereby the phase characteristics ∠H(f) of a desired transfer function indicated by the solid line in FIG. **5** are obtained.

The phase characteristics ∠H(f) of the transfer function determined from the measurement performed under water as described above depend on the transfer characteristics of the ultrasonic transducer device **200**. Accordingly, it is possible to determine in advance the phase characteristics ∠H(f) of the transfer function of each ultrasonic transducer device **200** through measurement performed under water and store the determined phase characteristics ∠H(f) in the characteristics information storage unit **150**. By doing so, highly accurate phase characteristics ∠H(f) including variations in the characteristics of the ultrasonic transducer device **200** can be obtained.

With the ultrasonic measuring device **100** of this embodiment, the amplitude of the transfer function can be determined based on reception signals from at least three areas in the test subject. Furthermore, it is unnecessary to perform processing, such as determining a cepstrum so as to remove dips included in the power spectra of the reception signals, and thus the amplitude of the transfer function can be determined in a short processing time. Furthermore, the transfer function that also includes phase characteristics in addition to the amplitude can be used, and it is therefore possible to efficiently generate an ultrasonic image having a higher spatial resolution.

3. Deconvolution Filter

The ultrasonic measuring device **100** of this embodiment performs filter processing using a deconvolution filter by using the amplitude |H(f)| and the phase characteristics ∠H(f) of the transfer function determined in the above-described manner.

The deconvolution filter is, for example, a Wiener filter M(ω) as shown below.

[Math. 1]

$$M(\omega) = \frac{H(\omega)^*}{|H(\omega)|^2 + \beta \cdot Pn(\omega)/Pf(\omega)} \quad (1)$$

where ω represents an angular frequency, H*(ω) represents the complex conjugate of the transfer function H(ω), |H(ω)| represents the amplitude of the transfer function H(ω), Pn(ω) represents the power spectrum of noise components of reception signals, Pf(ω) represents the power spectrum of signal components of reception signals, and β represents an adjustment factor value.

Pn(ω)/Pf(ω) in Equation (1) corresponds to the inverse of an S/N (signal-to-noise ratio). That is, Pn(ω)/Pf(ω) becomes closer to 0 as the S/N becomes higher, and becomes closer to infinity as the S/N becomes lower. Accordingly, the Wiener filter M(ω) given by Equation (1) is as follows.

$$M(\omega) \rightarrow 1/H(\omega) \text{ (when the S/N is high)} \quad (2)$$

$$M(\omega) \rightarrow 0 \text{ (when the S/N is low)} \quad (3)$$

As can be seen from Expressions (2) and (3), the Wiener filter M(ω) efficiently works in a frequency region having a high S/N. That is, the Wiener filter M(ω) has the effect of suppressing amplification of noise.

Pf(ω) representing the power spectrum of signal components and Pn(ω) representing the power spectrum of noise components can be determined from two or more ultrasonic images (B mode images) measured at different time instants.

For example, with respect to each of single-frame images IM**1**, IM**2** and IM**3** measured respectively at time instants t**1**, t**2** and t**3**, power spectra PS**1**(ω), PS**2**(ω) and PS**3**(ω) of reception signals corresponding to the first, second and third scan lines are obtained. Next, an average value of the power spectrum PS**1**(ω) obtained from the image IM**1**, the power spectrum PS**1**(ω) obtained from the image IM**2**, and the power spectrum PS**1**(ω) obtained from the image IM**3** is obtained. That is, a time average value Av_PS**1**(ω) of the power spectra PS**1**(ω) at time instants t**1**, t**2** and t**3** is determined. In the same way, a time average value Av_PS**2**(ω) of the power spectra PS**2**(ω) at the time instants t**1**, t**2** and t**3**, and a time average value Av_PS**3**(ω) of the power spectra PS**3**(ω) at the time instants t**1**, t**2** and t**3** is determined. Then, an average value of the three time average values Av_PS**1**(ω), Av_PS**2**(ω) and Av_PS**3**(ω) is obtained, which is defined as the power spectrum Pf(ω) of signal components.

Pn(ω) representing the power spectrum of noise components can be determined as follows. A variance Dp_PS**1**(ω) is determined with respect to the power spectra PS**1**(ω) at the time instants t**1**, t**2** and t**3**. In the same way, variances Dp_PS**2**(ω) and Dp_PS**2**(ω) are determined with respect to the power spectra PS**2**(ω) and PS**3**(ω) at the time instants t**1**, t**2** and t**3**. Then, an average value of the three variances Dp_PS**1**(ω), Dp_PS**2**(ω) and Dp_PS**2**(ω) is determined, which is defined as the power spectrum Pn(ω) of noise components.

In the single-frame images IM**1**, IM**2** and IM**3** measured at the time instants t**1**, t**2** and t**3**, if the target subject or the ultrasonic probe is moving, the time average values Av_PS**1**(ω), Av_PS**2**(ω) and Av_PS**3**(ω) are not appropriately calculated. Accordingly, it is desirable to take measurement in a state in which the target subject or the ultrasonic probe is not moving. The state in which the target subject or the ultrasonic probe is not moving may be detected by using a tracking technique, or the movement of the target subject or the ultrasonic probe may be canceled.

In the foregoing, an example was described in which the power spectrum Pf(ω) of signal components and the power spectrum Pn(ω) of noise components are determined based on three images (frames) measured at different time instants, but the number of images is not limited to 3. The number of images (the number of frames) may be 2, or may be 4 or more as long as they are measured at different time instants.

The adjustment factor β is provided to adjust the degree of the effect of suppressing the amplification of noise. As can be seen from Equation (1), if the adjustment factor β takes a great value, the widening of bandwidth of the signal after filter processing is suppressed, and the amplification of noise is also suppressed. If, on the other hand, the adjustment factor β takes a small value, the widening of bandwidth of the signal after filter processing is prioritized, but noise is also amplified.

In the ultrasonic measuring device **100** of this embodiment, the adjustment factor β can be determined by performing ultrasonic measurement on a wire under water. Specifically, filter processing using a deconvolution filter (Wiener filter) is performed on the obtained reception signal by using the transfer function H(ω) of the ultrasonic transducer device **200** under water, the power spectrum Pn(ω) of

noise components and the power spectrum Pf(ω) of signal components. Then, the adjustment factor β is determined such that the half-value width of the amplitude of the processed signal be minimum. The adjustment factor value β is, for example, 0.2 or less.

The characteristics information storage unit **150** can store adjustment factor values β determined based on the results of measurement performed in advance under water. By doing so, the processing unit **130** can perform filter processing using a deconvolution filter by using an adjustment factor value β stored in the characteristics information storage unit **150**.

Also, the characteristics information storage unit **150** can store, as the adjustment factor value β, values that are different depending on the ultrasonic transducer device **200** or the test subject. By doing so, the processing unit **130** can perform filter processing using a deconvolution filter by using the adjustment factor value β that varies depending on the ultrasonic transducer device **200** or the test subject.

Also, the processing unit **130** may perform filter processing using a deconvolution filter by using an adjustment factor value β received by the input receiving unit **160**. By doing so, the user can set the adjustment factor value β.

The deconvolution filter used in the ultrasonic measuring device **100** of this embodiment is not limited to the Wiener filter described above. It is also possible to use, for example, Lucy-Richardson method, a regularization filter, or the like.

FIGS. **6**A and **6**B show an example of the adjustment factor β. FIG. **6**A shows a relationship between the half-value width of the amplitude of the signal after filter processing and the adjustment factor β. FIG. **6**B shows the signal voltage and the half-value width of the signal amplitude before and after filter processing.

As can be seen from FIG. **6**A, the half-value width becomes smaller as the adjustment factor β decreases, but when the adjustment factor β takes a value that is too close to 0, the half-value width increases. In the example shown in FIG. **6**A, the half-value width becomes minimum when the adjustment factor β takes a value of 0.01706. Then, as shown in FIG. **6**B, the half-value width of the amplitude of the signal after processing is reduced as compared to that before processing.

4. Flow of Filter Processing

A flow of filter processing using a deconvolution filter in the first configuration example of the ultrasonic measuring device **100** of this embodiment will be described. The flow of processing described below is executed by the processing unit **130**. The processing unit **130** performs processing for determining a deconvolution filter as preliminary processing, and performs processing for performing filter processing on reception signals so as to generate image data based on the processed signals as main processing.

FIG. **7** shows an example of a flowchart of preliminary processing performed by the processing unit **130**. First, the processing unit **130** performs ultrasonic measurement so as to acquire m ultrasonic images at different time instants t**1**, t**2** . . . , and tm (where m is an integer of 2 or greater) (step S**1**). Next, the processing unit **130** makes comparison between the acquired m ultrasonic images, and determines whether or not the target subject or the ultrasonic probe is moving (steps S**2** and S**3**). For example, the processing unit **130** can determine whether or not the target subject or the ultrasonic probe is moving by performing processing for extracting feature points from each of m ultrasonic images, and associating the extracted feature points. If the processing unit **130** determines that the target subject or the ultrasonic probe is moving, the procedure returns to step S**1**, where ultrasonic measurement is again performed. If the processing unit **130** determines that the target subject or the ultrasonic probe is not moving, the procedure advances to step S**4**.

In step S**4**, the processing unit **130** performs fast Fourier transformation on reception signals RS**1** to RSn corresponding to n (where n is an integer of 3 or greater) scan lines of each ultrasonic image, so as to obtain power spectra PS**1** to PSn. Next, with respect to the power spectra PS**1** to PSn, the processing unit **130** determines the time average value and variance at the time instants t**1** to tm (step S**5**). Then, the time average values and variances of the power spectra PS**1** to PSn are averaged by n scan lines, thereby the power spectrum Pf(ω) of signal components and the power spectrum Pn(ω) of noise components are determined (step S**6**).

Next, the processing unit **130** averages the power spectra PS**1** to PSn, and determines the square root thereof so as to obtain the amplitude |H(f)| of a transfer function (step S**7**). Then, the processing unit **130** reads the phase characteristics ∠H(f) of the transfer function and the adjustment factor β from the characteristics information storage unit **150** (step S**8**). The processing unit **130** determines a deconvolution filter M(ω) by using the amplitude |H(f)| of the transfer function determined as described above, and the phase characteristics ∠H(f), the power spectrum Pf(ω) of signal components, the power spectrum Pn(ω) of noise components, and the adjustment factor β (step S**9**).

The preliminary processing may be performed on each frame image, or may be performed on a plurality of frame images. In the case where the preliminary processing is performed on a plurality of frame images, filter processing is performed on reception signals corresponding to the plurality of frame images by using a deconvolution filter determined through the preliminary processing.

FIG. **8** shows an example of a flowchart of main processing performed by the processing unit **130**. First, the processing unit **130** sets a variable i representing the scan line number to an initial value of 1 (step S**11**). Next, the processing unit **130** reads a reception signal RSi corresponding to the measured i-th scan line from the storage unit **140** (step S**12**). Then, the processing unit **130** performs filter processing on the reception signal RSi by using the deconvolution filter M(ω) determined in the preliminary processing (step S**13**).

Next, the processing unit **130** performs absolute value processing on the reception signal that has undergone the filter processing (step S**14**), then performs envelope detection processing (step S**15**), and thereafter performs intensity modulation processing so as to generate image data corresponding to the i-th scan line (step S**16**). Then, the processing unit **130** stores the image data corresponding to the i-th scan line in a memory area corresponding to the i-th scan line in an image data memory in the storage unit **140** (step S**17**).

Next, the processing unit **130** determines whether or not all scan lines of the ultrasonic image have undergone filter processing and image data generation processing (step S**18**). If not all scan lines of the ultrasonic image have undergone filter processing and image data generation processing, the processing unit **130** increments the variable i (step S**19**), and performs processing on a reception signal corresponding to the next scan line (steps S**12** to S**17**). If all scan lines of the ultrasonic image have undergone filter processing and image data generation processing, the processing unit **130** performs processing for displaying one frame's worth of image data on the display unit **410** (step S**20**).

5. Identification of Transfer Function According to Second Configuration Example

FIGS. **9**A and **9**B are diagrams illustrating identification of a transfer function in a second configuration example of the ultrasonic measuring device **100** of this embodiment. In the second configuration example, the processing unit **130** can identify first to n-th transfer functions H**1**(ω) to Hn(ω) corresponding to first to n-th areas DP**1** to DPn (where n is an integer of 2 or greater) having different depths in the test subject. Then, filter processing is performed using first to n-th deconvolution filters M**1**(ω) to Mn(ω) corresponding to the first to n-th areas.

In FIGS. **9**A and **9**B, an example will be described in which first, second and third transfer functions H**1**(ω), H**2**(ω) and H**3**(ω) that correspond to first, second and third areas DP**1**, DP**2** and DP**3** having different depths in the test subject are identified.

FIG. **9**A shows, as in FIG. **2**A, ultrasonic beams BM**1**, BM**2** and BM**3** radiated to first, second and third areas P**1**, P**2** and P**3** in the test subject, and ultrasonic echoes EC**1**, EC**2** and EC**3** corresponding thereto. FIG. **9**B shows, as in FIG. **2**B, first, second and third scan lines SC**1**, SC**2** and SC**3** of one frame of ultrasonic image. First, second and third reception signals RS**1**, RS**2** and RS**3** are reception signals corresponding to the first, second and third scan lines SC**1**, SC**2** and SC**3** of the ultrasonic image.

The processing unit **130** performs frequency analysis on a time domain waveform corresponding to the first area DP**1** among the first, second and third reception signals RS**1**, RS**2** and RS**3**, so as to obtain power spectra PS**1**(f), PS**2**(f) and PS**3**(f). Then, the power spectra PS**1**(f), PS**2**(f) and PS**3**(f) are averaged, and the square root of the averaged power spectrum is defined as the amplitude |H**1**(f)| of the transfer function of the first area DP**1**.

Likewise, the processing unit **130** performs frequency analysis on a time domain waveform corresponding to the second area DP**2** among the first, second and third reception signals RS**1**, RS**2** and RS**3**, so as to obtain power spectra PS**1**(f), PS**2**(f) and PS**3**(f). Then, the power spectra PS**1**(f), PS**2**(f) and PS**3**(f) are averaged, and the square root of the averaged power spectrum is defined as the amplitude |H**2**(f)| of the transfer function of the second area DP**2**. The same processing is performed on the third area DP**3**, so as to obtain the amplitude |H**3**(f)| of the transfer function of the third area DP**3**.

The processing unit **130** performs filter processing by using deconvolution filters M**1**(ω), M**2**(ω) and M**3**(ω) including the transfer functions H**1**(ω), H**2**(ω) and H**3**(ω) identified in the manner described above. Specifically, with respect to the first area DP**1**, filter processing is performed using the first deconvolution filter M**1**(ω). With respect to the second area DP**2**, filter processing is performed using the second deconvolution filter M**2**(ω). With respect to the third area DP**3**, filter processing is performed using the third deconvolution filter M**3**(ω).

The processing unit **130** can determine the power spectrum Pf(ω) of signal components and the power spectrum Pn(ω) of noise components for each of the first, second and third areas DP**1**, DP**2** and DP**3**. For example, the power spectrum Pf(ω) of signal components that corresponds to the first area DP**1** can be determined from the power spectra of reception signals corresponding to the first area DP**1** of two or more ultrasonic images measured at different time instants.

The reception signals to be subjected to filter processing are reception signals used to generate an ultrasonic image, and may include the reception signals RS**1** to RSn measured in the preliminary processing, or may not include them.

In this way, with the second configuration example of the ultrasonic measuring device **100**, filter processing can be performed by using a deconvolution filter corresponding to each of a plurality of areas having different depths in the test subject, and it is therefore possible to obtain a more highly accurate ultrasonic image.

6. Third Configuration Example of Ultrasonic Measuring Device

In the case where a thin film piezoelectric element is used as the ultrasonic transducer element, a dip may occur at a specific frequency that depends on the material or thickness of a back plate in the power spectrum of ultrasound radiated from the element. With a third configuration example of the ultrasonic measuring device **100** of this embodiment, the processing unit **130** detects the presence or absence of such a dip, whereby it is possible to determine whether or not the preliminary processing for identifying the amplitude of the transfer function has been appropriately executed.

FIGS. **10**A and **10**B show an example of a basic configuration of an ultrasonic transducer element **10** (thin-film piezoelectric ultrasonic transducer element) of the ultrasonic transducer device **200**. The ultrasonic transducer element **10** includes a vibration film **42** and a piezoelectric element unit. The piezoelectric element unit includes a first electrode layer **21**, a piezoelectric film **30**, and a second electrode layer **22**. The configuration of the ultrasonic transducer element **10** of this embodiment is not limited to that shown in FIGS. **10**A and **10**B, and various modifications can be carried out, such as omitting some of the constituent elements, replacing some of the constituent elements with other constituent elements, and adding other constituent elements.

FIG. **10**A is a plan view of the ultrasonic transducer element **10** formed on a substrate **60** (silicon substrate), as viewed from a direction normal to the surface of the substrate on which the element is formed. FIG. **10**B is a cross-sectional view showing a cross section taken along the line A-A' shown in FIG. **10**A.

The first electrode layer **21** (lower electrode) is formed by a thin metal film on a top layer of the vibration film **42**. As shown in FIG. **10**A, the first electrode layer **21** may be an interconnect that extends to outside the element forming region and is connected to an adjacent ultrasonic transducer element **10**.

The piezoelectric film **30** (piezoelectric layer) is formed by, for example, a PZT (lead zirconate titanate) thin film provided so as to cover at least a part of the first electrode layer **21**. The material of the piezoelectric film **30** is not limited to PZT, and it is also possible to use, for example, lead titanate ($PbTiO_3$), lead zirconate ($PbZrO_3$), lead lanthanum titanate ($(Pb, La)TiO_3$), and the like.

The second electrode layer **22** (upper electrode) is formed by, for example, a thin metal film provided so as to cover at least a part of the piezoelectric film **30**. As shown in FIG. **10**A, the second electrode layer **22** may be an interconnect that extends to outside the element forming region and is connected to an adjacent ultrasonic transducer element **10**.

The vibration film **42** (membrane) has a two-layer structure of, for example, a SiO_2 thin film and a ZrO_2 thin film, and is provided so as to close an opening **45**. The vibration film **42** supports the piezoelectric film **30** and the first and second electrode layers **21** and **22**, and is capable of generating ultrasound by being vibrated by extension and contraction of the piezoelectric film **30**.

The opening **45** is provided in the substrate **60**. A hollow region **40** formed by the opening **45** is formed by etching the

back surface (the surface on which the element is not formed) of the substrate **60** by reactive ion etching (RIE) or the like. The resonance frequency of ultrasound is determined by the size of the vibration film **42** allowed to vibrate as a result of the hollow region **40** being formed, and the ultrasound is radiated toward the piezoelectric film **30** (from the rear side toward the front in FIG. **10**A).

The lower electrode of the ultrasonic transducer element **10** is formed by the first electrode layer **21**, and the upper electrode thereof is formed by the second electrode layer **22**. Specifically, a portion of the first electrode layer **21** that is covered by the piezoelectric film **30** serves as the lower electrode, and a portion of the second electrode layer **22** that covers the piezoelectric film **30** serves as the upper electrode. That is, the piezoelectric film **30** is sandwiched between the lower electrode and the upper electrode.

The piezoelectric film **30** extends and contracts in an in-plane direction by application of voltage between the lower electrode and the upper electrode, or in other words, between the first electrode layer **21** and the second electrode layer **22**. The ultrasonic transducer element **10** has a monomorph (unimorph) structure in which a thin piezoelectric element unit and a vibration film **42** are bonded together, and thus when the piezoelectric element unit extends and contracts within the plane, the vibration film **42** bonded thereto is curved because the size of the vibration film **42** does not change. Accordingly, application of an alternating current voltage to the piezoelectric film **30** causes the vibration film **42** to vibrate in a thickness direction thereof, thereby ultrasound is radiated by the vibrations of the vibration film **42**. The voltage applied to the piezoelectric film **30** is, for example, 10 to 30 V, and the frequency is, for example, 1 to 10 MHz.

A bulk ultrasonic transducer element has a peak-to-peak driving voltage of approximately 100 V, but the peak-to-peak driving voltage of the thin-film piezoelectric ultrasonic transducer element as shown in FIGS. **10**A and **10**B can be reduced to approximately 10 to 30 V.

The ultrasonic transducer element **10** also functions as a reception element that receives an ultrasonic echo obtained as a result of ultrasound being radiated from the element and reflected back from the target subject. The ultrasonic echo causes the vibration film **42** to vibrate, and in response to the vibration, stress is applied to the piezoelectric film **30** to generate voltage between the lower electrode and the upper electrode. The generated voltage can be taken out as a reception signal.

The back surface (the surface on which the element is not formed) of the substrate **60** is provided with a back plate (reinforcing member) (not shown). The back plate is a member for reinforcing the substrate **60** to protect it from mechanical impact. Due to part of ultrasound being absorbed by the back plate, a dip occurs at a specific frequency that depends on the material or thickness of the back plate.

FIG. **11** shows a configuration example of the ultrasonic transducer device **200** of this embodiment. The ultrasonic transducer device **200** of this configuration example includes a plurality of ultrasonic transducer elements **10** arranged in an array, first to n-th (where n is an integer of 2 or greater) driving electrode lines DL**1** to DLn, and first to m-th (where m is an integer of 2 or greater) common electrode lines CL**1** to CLm. FIG. **11** shows an example in which m=8, and n=12, but they may take values other than these. Note that the configuration of the ultrasonic transducer device **200** of this embodiment is not limited to that shown in FIG. **11**, and various modifications can be carried out, such as omitting some of the constituent elements, replacing some of the constituent elements with other constituent elements, and adding other constituent elements.

The plurality of ultrasonic transducer elements **10** are arranged in a matrix having m rows and n columns. For example, as shown in FIG. **11**, eight rows are provided in the X direction, and twelve columns are provided in a Y direction intersecting the X direction. The ultrasonic transducer elements **10** may have a configuration as shown in FIGS. **10**A and **10**B, for example.

First to twelfth (n-th in a broad sense) driving electrode lines DL**1** to DL**12** are disposed in the X direction. Among the first to twelfth driving electrode lines DL**1** to DL**12**, a j-th (where j is an integer that satisfies $1 \leq j \leq 12$) driving electrode line DLj is connected to first electrodes of the ultrasonic transducer elements **10** disposed in the j-th column.

During an emission period in which ultrasound is radiated, first to twelfth emission signals VT**1** to VT**12** output by an emission unit **110**, which will be described later, are supplied to respective ultrasonic transducer elements **10** via the driving electrode lines DL**1** to DL**12**. During a reception period in which ultrasonic echo signals are received, reception signals VR**1** to VR**12** from the ultrasonic transducer elements **10** are output to a reception unit **120**, which will be described later, via the driving electrode lines DL**1** to DL**12**.

First to eighth (m in a broad sense) common electrode lines CL**1** to CL**8** are provided in the Y direction. A second electrode of an ultrasonic transducer element **10** is connected to any one of the first to m-th common electrode lines CL**1** to CLm. Specifically, for example, as shown in FIG. **11**, among the first to eighth common electrode lines CL**1** to CL**8**, an i-th (where i is an integer that satisfies $1 \leq i \leq 8$) common electrode line CLi is connected to the second electrodes of the ultrasonic transducer elements **10** disposed in the i-th column.

A common voltage VCOM is supplied to the first to eighth common electrode lines CL**1** to CL**8**. It is sufficient that the common voltage is a constant direct current voltage, and it does not necessarily need to be 0 V, or in other words, the ground potential (earth potential).

For example, with respect to the ultrasonic transducer element **10** located in the first column of the first row, its first electrode is connected to the driving electrode line DL**1**, and its second electrode is connected to the first common electrode line CL**1**. Likewise, with respect to the ultrasonic transducer element **10** located in, for example, the sixth column of the fourth row, its first electrode is connected to the sixth driving electrode line DL**6**, and its second electrode is connected to the fourth common electrode line CL**4**.

The arrangement of the ultrasonic transducer elements **10** is not limited to the arrangement in a matrix having m rows and n columns shown in FIG. **11**. It is possible to use a so-called staggered arrangement in which, for example, m ultrasonic transducer elements **10** are arranged in odd number columns, and m−1 ultrasonic transducer elements **10** are arranged in even number columns.

The elements in which a dip occurs in the frequency characteristics of the radiated ultrasound due to the back plate are not limited to the above-described thin film piezoelectric elements, and may be other thin film elements such as, for example, capacitive micromachined ultrasonic transducer (CMUT) elements.

FIG. **12** shows an example of a power spectrum of ultrasound radiated from a thin-film piezoelectric ultrasonic transducer element. As can be seen from FIG. **12**, the occurrence of a significant dip is observed at a specific

frequency. The frequency at which the dip is observed depends on the material or thickness of the back plate.

As shown in FIGS. **3**A and **3**B, the power spectra of reception signals include dips caused by interference of a plurality of reflected ultrasonic waves from the test subject, but such dips can be smoothened by averaging the power spectra. In the case of a dip caused due to the back plate as shown in FIG. **12** as well, the dip can be removed by averaging the power spectra. Accordingly, in processing for determining the amplitude of the transfer function (for example, step S**7** shown in FIG. **7**), if a dip is observed as a result of the power spectra PS**1** to PSn being averaged, it indicates a possibility that some kind of problem has occurred in the ultrasonic measurement, or in the analysis of reception signals.

FIG. **13** shows an example of a flowchart of preliminary processing according to the third configuration example. The processing shown in FIG. **13** is executed by the processing unit **130**. Processing in steps S**21** to S**27** shown in FIG. **13** is the same as the processing (steps S**1** to S**7** shown in FIG. **7**) according to the first configuration example described above, and thus a detailed description thereof is not given here.

The processing unit **130** determines whether or not there is a dip in the result obtained by averaging the power spectra PS**1** to PSn (step S**28**). Specifically, for example, if a P_{dip}/P_{peak} ratio, which is the ratio between a power value P_{dip} at each frequency and a peak power value P_{peak}, is smaller than a predetermined value Pa, the processing unit **130** determines that there is a dip. If, on the other hand, the P_{dip}/P_{peak} ratio is greater than or equal to the predetermined value Pa, the processing unit **130** determines that there is no dip.

If the processing unit **130** determines that there is no dip, the processing unit **130** reads, from the characteristics information storage unit **150**, the phase characteristics ∠H(f) of the transfer function and the adjustment factor value β (step S**29**), and determines a deconvolution filter M(ω) (step S**30**). If, on the other hand, the processing unit **130** determines that there is a dip, the processing unit **130** determines that an error has occurred (step S**31**), and performs processing such as displaying a screen informing the user of the occurrence of the error on the display unit **410**.

As described above, with the third configuration example of the ultrasonic measuring device **100** of this embodiment, the presence or absence of a dip caused due to the back plate is detected by the processing unit **130**, and thus it is possible to determine whether or not the preliminary processing has been appropriately executed. Consequently, highly reliable ultrasonic measurement can be performed.

7. Ultrasonic Image Device

FIGS. **14**A and **14**B show examples of specific configurations of the ultrasonic image device **400** of this embodiment. FIG. **14**A shows a portable ultrasonic image device **400**, and FIG. **14**B shows a stationary ultrasonic image device **400**.

The portable and stationary ultrasonic image devices **400** both include the ultrasonic measuring device **100**, an ultrasonic probe **300**, a cable **350**, and the display unit **410**. The ultrasonic probe **300** includes the ultrasonic transducer device **200** and is connected to the ultrasonic measuring device **100** via the cable **350**. The display unit **410** displays display image data.

At least a portion of the emission unit **110**, the reception unit **120**, and the processing unit **130** of the ultrasonic measuring device **100** can be provided in the ultrasonic probe **300**.

FIG. **14**C shows an example of the specific configuration of the ultrasonic probe **300** of this embodiment. The ultrasonic probe **300** includes a probe head **315** and a probe body **320**, and as shown in FIG. **14**C, the probe head **315** is detachable from the probe body **320**.

The probe head **315** includes the ultrasonic transducer device **200**, a probe base **311**, a probe housing **312**, and a probe head-side connector **313**.

The probe body **320** includes a probe body-side connector **323**. The probe body-side connector **323** is connected to the probe head-side connector **313**. The probe body **320** is connected to the ultrasonic measuring device **100** via the cable **350**. Note that at least a portion of the emission unit **110** and the reception unit **120** of the ultrasonic measuring device **100** can be provided in the probe body **320**.

Note that although various embodiments have been explained in detail above, a person skilled in the art will readily appreciate that it is possible to implement numerous variations and modifications that do not depart substantially from the novel aspects and effect of the invention. Accordingly, all such variations and modifications are also to be included within the scope of the invention. For example, terms that are used within the description or drawings at least once together with broader terms or alternative synonymous terms can be replaced by those other terms at other locations as well within the description or drawings. Also, the configuration and operation of the ultrasonic measuring device and the ultrasonic image device, and the method for processing an ultrasonic image are not limited to those described in the embodiments, and various modifications are possible.

The entire disclosure of Japanese Patent Application No. 2013-116175, filed May 31, 2013 is expressly incorporated by reference herein.

What is claimed is:

1. An ultrasonic measuring device comprising:
an ultrasonic transducer device; and
a processor configured to
perform processing for emitting an ultrasonic beam,
perform processing for receiving an ultrasonic echo, which is obtained as a result of the ultrasonic beam being reflected by a test subject, and
perform processing based on reception signals obtained by receiving the ultrasonic echo,
wherein the processor identifies a transfer function with respect to the ultrasonic transducer device and the test subject based on a first reception signal corresponding to an ultrasonic echo of an ultrasonic beam radiated to a first area in the test subject, a second reception signal corresponding to an ultrasonic echo of an ultrasonic beam radiated to a second area in the test subject, and a third reception signal corresponding to an ultrasonic echo of an ultrasonic beam radiated to a third area in the test subject, the third area being located between the first area and the second area, and
performs ultrasonic image generation processing including filter processing using a deconvolution filter including the transfer function performed on the reception signals.

2. The ultrasonic measuring device according to claim **1**,
wherein the processor obtains a first power spectrum of the first reception signal, a second power spectrum of the second reception signal, and a third power spectrum of the third reception signal, and
determines an amplitude of the transfer function from the first power spectrum, the second power spectrum, and the third power spectrum.

3. The ultrasonic measuring device according to claim 2, comprising:

a storage device that stores information regarding phase characteristics of a transfer function with respect to the ultrasonic transducer device,

wherein the processor performs the filter processing using a deconvolution filter by using the information regarding phase characteristics of the transfer function with respect to the ultrasonic transducer device stored in the storage device, and the amplitude of the transfer function determined from the first reception signal, the second reception signal, and the third reception signal.

4. The ultrasonic measuring device according to claim 3, wherein $M(\omega)=H^*(\omega)/(|H(\omega)|^2+\beta\times Pn(\omega)/Pf(\omega))$, where ω represents an angular frequency, $|H(\omega)|$ represents the amplitude of the transfer function, $H^*(\omega)$ represents a complex conjugate of the transfer function, $Pn(\omega)$ represents a power spectrum of noise components of the reception signals, $Pf(\omega)$ represents a power spectrum of signal components of the reception signals, β represents an adjustment factor value, and $M(\omega)$ represents the deconvolution filter.

5. The ultrasonic measuring device according to claim 4, wherein the storage device further stores the adjustment factor value β, and

the processor performs the filter processing using a deconvolution filter by using the adjustment factor value β stored in the storage device.

6. The ultrasonic measuring device according to claim 5, wherein the storage device stores, as the adjustment factor value β, different values depending on the ultrasonic transducer device or the test subject.

7. The ultrasonic measuring device according to claim 6, wherein the processor performs the filter processing using a deconvolution filter by using the adjustment factor value β that varies depending on the ultrasonic transducer device or the test subject.

8. The ultrasonic measuring device according to claim 4, wherein the adjustment factor value β is 0.2 or less.

9. The ultrasonic measuring device according to claim 4, comprising:

an input device that receives input of information regarding the adjustment factor value β,

wherein the processor performs the filter processing using a deconvolution filter by using the information regarding the adjustment factor value β received by the input device.

10. The ultrasonic measuring device according to claim 4, wherein the processor determines the power spectrum $Pf(\omega)$ of the signal components based on time average values of power spectra of a plurality of reception signals measured at different time instants, and

determines the power spectrum $Pn(\omega)$ of the noise components based on variances of the power spectra of the plurality of reception signals measured at the different time instants.

11. The ultrasonic measuring device according to claim 1, wherein the processor identifies a first transfer function to an n-th transfer function with respect to a first area to an n-th area (where n is an integer of 2 or greater) that have different depths in the test subject, and performs the filter processing by using a first deconvolution filter to an n-th deconvolution filter including the first transfer function to the n-th transfer function with respect to the first area to the n-th area.

12. The ultrasonic measuring device according to claim 1, wherein the first area in the test subject is an area corresponding to a first edge of the ultrasonic image,

the second area in the test subject is an area corresponding to a second edge of the ultrasonic image that is located opposite to the first edge, and

the third area in the test subject is an area located between the first edge and the second edge in the ultrasonic image.

13. An ultrasonic image device comprising:

the ultrasonic measuring device according to claim 1; and

a display device that displays the ultrasonic image.

14. An ultrasonic image device comprising:

the ultrasonic measuring device according to claim 2; and

a display device that displays the ultrasonic image.

15. An ultrasonic image device comprising:

the ultrasonic measuring device according to claim 3; and

a display device that displays the ultrasonic image.

16. An ultrasonic image device comprising:

the ultrasonic measuring device according to claim 4; and

a display device that displays the ultrasonic image.

17. An ultrasonic image device comprising:

the ultrasonic measuring device according to claim 5; and

a display device that displays the ultrasonic image.

18. An ultrasonic image device comprising:

the ultrasonic measuring device according to claim 6; and

a display device that displays the ultrasonic image.

19. An ultrasonic image device comprising:

the ultrasonic measuring device according to claim 7; and

a display device that displays the ultrasonic image.

20. An ultrasonic image processing method executed by a processor of an ultrasonic measuring device including: an ultrasonic transducer device; and the processor that performs processing for emitting an ultrasonic beam, that performs processing for receiving an ultrasonic echo, which is obtained as a result of the ultrasonic beam being reflected by a test subject and that performs processing based on reception signals obtained by receiving the ultrasonic echo, the method comprising:

identifying a transfer function with respect to the ultrasonic transducer device and the test subject based on a first reception signal corresponding to an ultrasonic echo of an ultrasonic beam radiated to a first area in the test subject, a second reception signal corresponding to an ultrasonic echo of an ultrasonic beam radiated to a second area in the test subject, and a third reception signal corresponding to an ultrasonic echo of an ultrasonic beam radiated to a third area in the test subject, the third area being located between the first area and the second area, and

performing filter processing using a deconvolution filter including the transfer function on the reception signals.

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